THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Managing the flows?

Furthering a socio-material flow methodology for industrial ecology

MATHIAS LINDKVIST

Department of Technology Management and Economics

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2019

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ISBN 978-91-7905-178-5

Doktorsavhandlingar vid Chalmers tekniska högskola
Ny serie nr 4645
ISSN 0346-718X

Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Goteborg
Sweden
Telephone + 46 (0)31-772 1000

Chalmers digitaltryck, Chalmers University of Technology
Gothenburg, Sweden 2019

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ABSTRACT

This dissertation defends the thesis that application of the socio-material methodology that I present can assist environmentally more effective decision-making. The methodology provides a recipe for a systematic and accurate understanding of how human actions determine environmental impacts via material (tangible) flows. The methodology combines engineering, interpretative, and critical studies of material flows, interactions between humans and material objects, and nets of human interaction. This approach extends existing industrial ecology methods on quantitative models of actors, and the limited methodological consideration in studies that connect social and material aspects. Within the dissertation, an introductory overview, a literature review, field studies, and a conceptual study support the methodology. The overview shows that earlier studies have illustrated that actors' different relations to material flows determine these flows. The review covered an analysis of other literature that shows the environmental relevance of complex relations between and conflicts among humans. This literature explicitly shows that mainstream industrial ecology may underestimate sustainability challenges by focusing too much on only material flows. The field studies are based on interviews, observation, and text studies for 17 different material flows and illustrate the efficiency of the methodology, its application to recycling, and that its use can reveal environmentally important human action that relate to the product flows of cement and packaging, among other. The findings include the identification of non-trivial organisational findings, such as the lack of coordination in the bread product chain resulting in the discarding of bread, and, in another study, the presence of 'free riders' distorting the governance of packaging recycling. Finally, the conceptual study both outlined concepts and procedures in the methodology, and its basis in a combination of the naturalistic, interpretative, and critical philosophy of science schools. Future research on the methodology could cover the use of the methodology for informing actual decision-making and an application to the suggested sustainability response economic degrowth.

Keywords: life cycle assessment (LCA), socio-material, actor-network-theory (ANT), action nets, methodology, field studies, conceptualisation, review, material flow, industrial ecology

LIST OF PAPERS IN THE DISSERTATION

The dissertation contains the following papers, referred to by Roman numerals in the text:

I Baumann, H, J Berlin, B Brunklaus, M Lindkvist, B Löfgren, and AM Tillman (2011). The usefulness of an actor's perspective in LCA. In M Finkbeiner (Ed), Towards life cycle sustainability management, pp 73–83. New York City: Springer.

II Lindkvist, M, and H Baumann (manuscript). Considering matters of concern versus matters of fact in industrial ecology. Submitted to *Journal of Industrial Ecology*.

III Lindkvist, M (2018). Screening of how the organisation of life cycle nodes influences environmental impacts: a methodology. *Journal of Cleaner Production 204*: 461–470. DOI: 10.1016/j.jclepro.2018.09.044.

IV Lindkvist, M, and H Baumann (2017). Analyzing how governance of material efficiency affects the environmental performance of product flows: a comparison of product chain organization of Swedish and Dutch metal packaging flows. *Recycling 2*(4): 23. DOI: 10.3390/recycling2040023.

V Baumann, H, and M Lindkvist (manuscript). Describing man-made flows. Outline of a socio-material flow methodology for industrial ecology. Submitted to *Journal of Industrial Ecology*.

Contributions by the author in the co-authored papers:

Paper I. All authors conceived of the presented idea. All authors contributed to the final manuscript, with BL as lead author.

Paper II. HB conceived of the investigated idea. All authors designed the study. ML carried out the data collection. All authors analysed the data. ML wrote the manuscript in consultation with HB.

Paper IV. All authors conceived of the investigated idea and designed the study. ML carried out the data collection. All authors contributed analysis tools and analysed the data. All authors wrote the paper.

Paper V. HB conceived of the presented idea. All authors designed the study. ML carried out the data collection. ML wrote the manuscript in consultation with HB.

OTHER PUBLICATIONS BY THE AUTHOR

2019:

Lindkvist, M, and H Baumann (2019). About adapting O-LCA to decision makers. *9th International Conference on Life Cycle Management*. 1–4 September 2019, Poznan, Poland.

2016:

Lindkvist, M, H Baumann, and M Ljunggren Söderman (2016). Complementing LCA with qualitative organisational study for improving waste management governance – illustrated by a comparative case on metal packaging. *Life Cycle Assessment and Other Assessment Tools for Waste Management and Resource Optimization*. 5–10 June 2016, Cetraro, Calabria, Italy.

2015:

Baumann, H, B Brunklaus, M Lindkvist, R Arvidsson, H Nilsson-Lindén, and J Hildenbrand (2015). Populating the life cycle perspective: methods for analyzing social and organizational dimensions of product chains for management studies. *8th Biennial Conference of the International Society for Industrial Ecology*. 7–10 July 2015, Guildford, UK.

Lindkvist, M, and H Baumann (2015). *The influence of organisational practices on environmental performance: a screening of the organising of nodes in product life cycles in six test cases*. Report / Division of Environmental Systems Analysis, Chalmers University of Technology, 2015:14. Göteborg: Chalmers University of Technology.

2014:

Lindkvist, M (2014). *The influence of management practices and policy on the environmental performance of metal packaging waste management: the cases of Sweden and the Netherlands*. Report - Department of Environmental Systems Analysis, Chalmers University of Technology, 2014:11. Göteborg: Chalmers University of Technology.

Lindkvist, M, and H Baumann (2014). *A review of social science in five industrial ecology journals*. Report / Division of Environmental Systems Analysis, Chalmers University of Technology, 2014:13. Göteborg: Chalmers University of Technology.

2013:

Lindkvist, M, and H Baumann (2013). Bring on the ‘soft’ sciences: exploring implications of grounding life cycle methods in three socio-material philosophies. *6th International Conference on Life Cycle Management*. 25-28 August 2013, Gothenburg, Sweden.

2010:

Lindkvist, M, and H Baumann (2010). The environmental significance of management practices: exploring the eco-efficiency of 6 cases. *14th ERSCP & 6th EMSU conference*. 25–29 October 2010, Delft, the Netherlands.

ACKNOWLEDGEMENTS

The thesis presented has only been possible to reach thanks to the persons and organisations that have supported the PhD project. My supervisor, Henrikke Baumann, has believed in me also when the PhD study process met difficulties. She enables my consideration of research aspects that I can easily overlook and that I believe are essential for tackling the research questions I find relevant to raise after the PhD project. My examiner Anne-Marie Tillman has provided support for the project as well as a sound down-to-earth perspective on processes and results. The realisation of this PhD project has been possible thanks to funding from the Swedish Research Council, J. Gust. Richerts Stiftelse, and Ragnar Sellbergs Stiftelse. Maria Ljunggren Söderman generously shared contact information of key people within the Swedish governance of recycling. I am happy for the feedback from members of the Organising for the Environment (OrM) and Organising and managing material flows (OMMF) seminar groups; in particular, Birgit Brunklaus, Petra Adolfsson, and Hanna Nilsson-Lindén have put time and effort into reviewing my manuscripts and draft presentations. Rickard Arvidsson has also provided valuable reviews of my manuscripts. Anders Hammer Strømman warmly welcomed me to work on this project at their premises for a year. Sverker Molander assisted me in securing access to vital infrastructure. Thanks to my other colleagues at ESA and IndEcol. To all others who have been part of the PhD project, thank you!

The more personal level has been just as important. My family, my friends, and Hui, thanks for everything!

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1 Introduction

This dissertation defends the thesis that application of the socio-material methodology that I present can assist environmentally more effective decision-making. The methodology provides a recipe for a systematic and accurate understanding of how human actions determine environmental impacts via material (tangible) flows. As a basis, the methodology combines engineering, interpretative (Braybrooke 2005), and critical (Braybrooke 2005) studies of material flows (e g, Deutz and Ioppolo 2015), interactions between humans and material objects, and nets of human interaction (see Figure 1). A socio-material flow methodology extends existing industrial ecology methods for environmental optimisation of quantified links between actors, such as in actor-based modelling (cf, e g, Romero and Ruiz 2014), and the limited methodological consideration in studies that connect social and material aspects (cf, e g, Wallsten and Krook 2016).

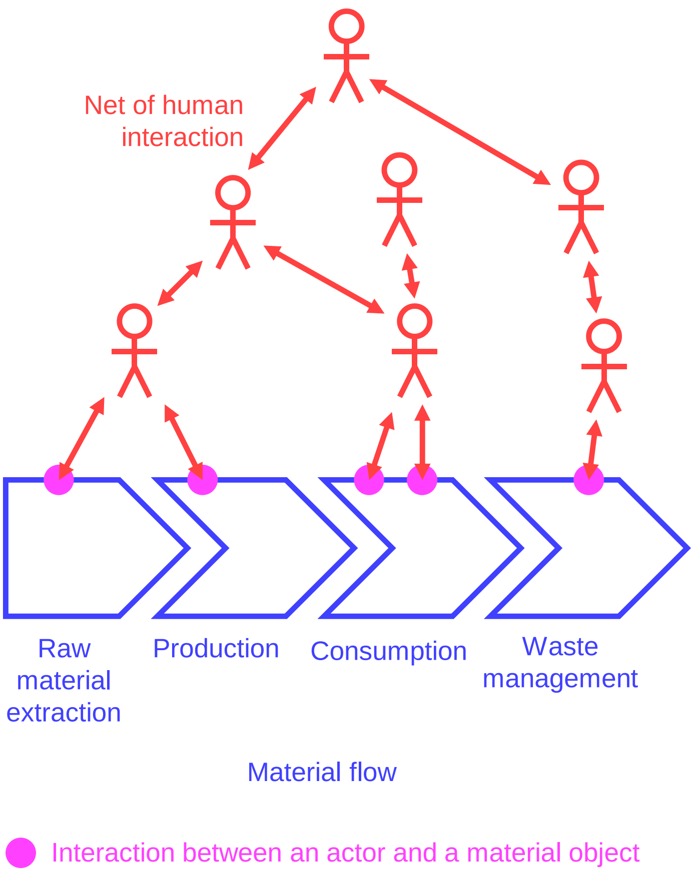

Figure 1: Material (tangible) objects and interaction that the socio-material methodology in this dissertation typically covers (this figure uses the example of a product flow).

The dissertation is a response to that the scientific literature clearly shows that environmental impacts from human activities seriously threaten both humans and the natural environment (e g, UN Environment 2019). For example, it has been stated that “[c]ontinuing to live on the brink of or outside of ecological limits, from the global to the local, will make it dramatically more difficult to achieve prosperity, justice, equity and a healthy life for all” (UN Environment 2019, p 4). Similarly, a United Nations publication of biodiversity concludes: “[n]ature across most of the globe has now been significantly altered by multiple human drivers, with the great majority of indicators of ecosystems and biodiversity showing rapid decline” (IPBES, p 4).

Considerable amounts of resources have been used for developing both knowledge and tools that can enable decreased environmental impacts. Cox et al (2016) has shown that a large number of theories have been formulated about natural resource management and governance. A range of tools that address the concerns have been developed in the academic field industrial ecology (Deutz and Ioppolo’s 2015).

One prominent contribution towards environmentally better handling the challenges is the study of *material flows* (e g, Hauschild et al 2018). A material flow is a system that consists of the use and transfers of the materials and energy needed in, for example, the raw material extraction, production, use, and waste management connected to a product’s function and the resulting environmental impacts (e g, Baumann and Tillman 2004). In this dissertation, I label these types of studies *material flow studies*. They been formalised for product functions (such as the heating of 1 m^3 indoor air to a certain temperature) in *life cycle assessment* (LCA) (e g, Hauschild et al 2018) and for the flows of specific materials in *material flow analysis* (MFA) (e g, Brunner and Rechberger 2017).

An LCA and an MFA study can provide input for avoiding environmental sub-optimisation within material flow systems. For example, an LCA could show that a reduction in the weight of a car through lighter materials and the subsequent effect on fuel consumption during the use phase might not lead to lower overall impact because of increased environmental impacts from the production of the lightweight materials. Material flow studies typically provide maps of flows that connect a large number of technical processes through long sequences of links and through many parallel links. The studies consider, in the case of LCA, the function of a flow system for humans, but do not give much explicit consideration to that the material flow depends on humans creating and maintaining the flows.

Life cycle management (LCM) is one approach that considers the management of flows of a product life cycle system (Sonnemann and Margni

2015a). LCM has been described as “a management concept applied in industrial and service sectors to improve products and services while enhancing the overall sustainability performance of business and its value chains” (Sonnemann and Margni 2015b). The LCM literature, however, primarily presents general suggestions about considering the entire material flow related to a product (Nilsson-Lindén et al 2018). Nilsson-Lindén et al (2018, p 7) have identified a lack of “descriptions or analyses of actual cases or of the difficulties involved in organizing LCM in practice”.

Environmentally oriented research has also been performed in social science studies of organisation and management (e g, George et al 2016). This research describes and analyses how humans act but covers only to a small degree the environmental impacts of the related material flows.

To address the deficiencies of these approaches, qualitative organisational studies and quantitative material flow studies have been initially combined in order to develop the methodology environmental assessment of organising (EAO) (Baumann 2004). A pilot study showed the environmental advantage of following a management style that was carefully adapted to specific building requirements contrary to an emergency-driven approach to energy and water flows in residential buildings (Brunklaus 2005). In addition, existing concepts about *socio-materiality* formed the basis for EAO (Baumann 2008). Socio-materiality refers to that material objects and humans are inseparable from each other.

Some research deals with both actors and flows, but not all actors in a flow system have equal opportunity to influence all parts of a flow system, as, for example, Shove (2018) has shown for actors along a flow and Löfgren (2009) for actors in one flow stage (production in Löfgren’s study). Shove pointed out that policy makers have found energy policies to be effective only because the policies focus on energy efficiency but not on total energy demand and supply. In sum, a methodology that better captures agency in flow models for better supporting sustainability intervention is needed.

Consequently, this dissertation presents and reasons about a thorough *socio-material flow methodology* that extends and formalises the EAO approach.

1.1 Aim of the doctoral project

This doctoral project has aimed to develop and test a methodology that applied can inform managers, policy-makers, researchers, and other actors more accurately than other approaches about how networks of human determine environmental impacts and change towards sustainability.

1.2 Research design

The thesis is based on research that spans from a question about the usefulness of the socio-material flow methodology to an outcome where a held-together version of the methodology is presented. Out of this trajectory came five papers that are part of this dissertation (see Figure 2) and for which I have performed major parts of the studies that they report and the writing.

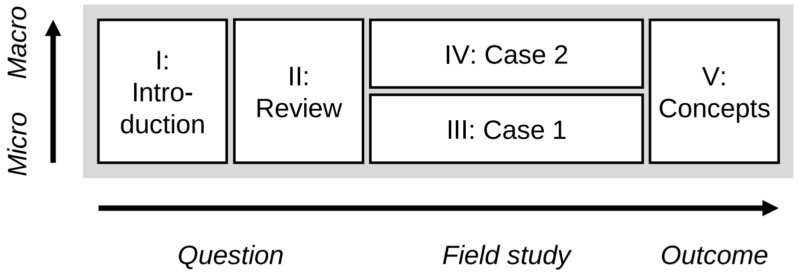

Figure 2: Overview of how Papers I–V support the thesis.

An overview of earlier studies on actors and LCA shows that the results that a standard LCA presents do not indicate which parts of the material flows that a specific actor can influence in practice (Paper I). Paper I also indicates that a more thorough methodology on human action and material flows can complement these spread earlier studies on actors and LCA. A literature review was performed to compare research on material flows with calls for thoroughly considering the interplay between humans and material objects (see Paper II). The calls have been central in developing the methodology. Two case studies were performed to develop different variants of the methodology and to test it on additional types of material flows (Papers III and IV). Paper III presents a micro-level study of how nets of humans determine the environmental performance of material flows in the services and products bowling, bread, coach services, concrete, and road management. Paper IV reports on a macro-level study of how humans involved in waste management of metal packaging create environmental impacts from material flows. Papers III and IV are based on interviews, observation, and studies of text sources. A conceptual study was carried out to develop a held-together version of the methodology and explore how established academic approaches, including ontologies, support the methodology (Paper V).

A further overview of the five papers and the relations between them is found in a chronological account on them in Chapter 5 and in summaries of their findings and methods in Chapter 7.

1.3 Outline

This chapter is followed by a presentation of the socio-material flow methodology with core conceptualisations, summaries of parts of the five papers, and discussion of relevance for the presented thesis. Chapter 2 introduces a few basic terms in order to present the essence of the methodology. Chapter 3 highlights the existence of fundamentally different research perspectives and their relevance for this dissertation. The chapter results in an ontology and an epistemology that both are interdisciplinary and represent the overarching research perspective that the methodology, and thus this dissertation and its writing style, follow. Chapter 4 discusses the academic contribution of the methodology through a broad review of related research areas. Chapter 5 presents an overview of the relationships between papers I–V, including an outline of the research journey of the doctoral project of which they are part. Chapter 6 thoroughly outlines the socio-material flow methodology. Chapter 7 outlines the findings and methods of each of the five papers that support the thesis. Chapter 8 presents a synthesis of the findings from these papers and discusses how different actors could use or support use of the methodology. Chapter 9 presents conclusions. Finally, Chapter 10 reasons about ideas on further research.

2. The essence of the socio-material flow approach

In this chapter, I briefly present a few concepts that can capture the essence of the socio-material flow methodology. The concepts cover life cycle assessment (LCA) (e g, Hauschild et al 2018), which is an analytical tool for addressing how a product's function relates to environmental impacts. The socio-material methodology uses LCA as a starting point for the description of the material flows that the socio-material methodology consider. LCA studies focus on the flows in a product life cycle, which is explained in the following. LCA and other material flow studies are often seen as part of the research field industrial ecology (Deutz and Ioppolo 2015) (see Figure 3), and, therefore, I reason about industrial ecology. I then outline ways that the methodology combines material flow studies with the other cornerstone of the methodology: organisational studies (e g, Robichaud and Cooren 2013). The combining is described through a more nuanced terminology than the in industrial ecology commonly used terms flow, stakeholder, and organisation. The methodology is further described in Chapter 6 and in Paper V.

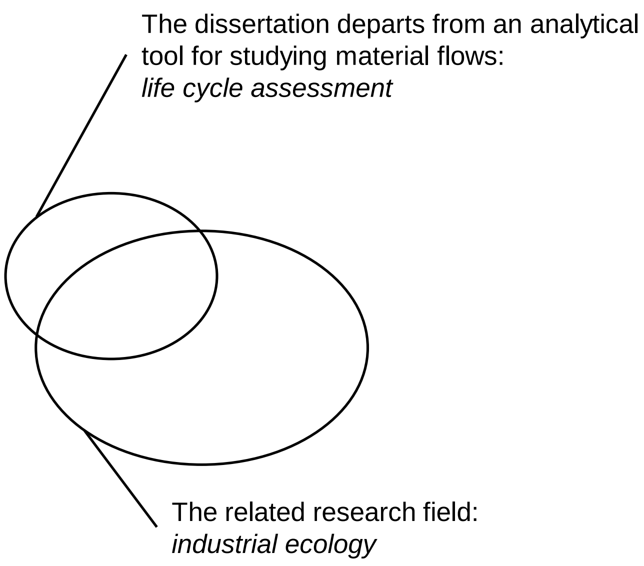

Figure 3: The socio-material flow methodology departs from an analytical tool and a related research field.

The socio-material flow methodology is based on *life cycle assessment* (LCA) because the approach highlights dependencies of environmental relevance along flows in consumption, production, and related technical processes. LCA is a tool for analysis of the environmental performance of the material flows related to a product (e g, Curran 2012). An LCA study covers as fully as possible the different resulting environmental impacts. These can include, for example, global warming and eutrophication. The tool is mainly based in engineering and the natural sciences.

The analysis in an LCA covers environmental impacts that stem from providing a product's function. The assessment includes impacts from the whole of or large parts of the product life cycle. The *product life cycle* consists of the different technical processes materially connected to a product, and typically stretches from raw material extraction, via production, use, and different transports, to waste processing,. A product life cycle can be compared to a supply chain, which is a widespread social science perspective (Ansari and Kant 2017). Both of them refer to the passing onwards of materials and energy related to products and via, for example, firms and consumers. However, the product life cycle is based on the material from an environmental point of view, while the supply chain is delimited by a business perspective. The product life cycle stretches all the way from raw material extraction and related technical processes to waste management. The supply chain often covers primarily one firm's direct suppliers and buyers and seldom go to the waste management beyond end users. In addition, the supply chain concerns the suppliers and buyers that are vital for a well-functioning distribution and a profitable business; the product life cycle specifically includes the most environmentally impacting material flows. The socio-material flow methodology follows product life cycles and other environmentally based material flows. The organisational processes to study are selected based on the flows.

LCA can be seen as mainly belonging to the research field *industrial ecology* (Deutz and Ioppolo 2015). Industrial ecology has become the field that gathers different types of analyses of the environmental performance of the material flows in consumption and production. Prominent ideas in the field are to recycle, to reuse, and to design production and consumption systems that use materials and energy as effectively as ecosystems – thus the name of the field. Research in the field is typically performed from an engineering and natural science perspective, but aspects about economics, management, and policy enter the field as well.

The socio-material flow methodology combines LCA with organisational studies. Only studying the *flows* leads to that much of their organisation and governance are assumed; material flows in consumption and production do not flow by themselves. The term flow is commonly used in industrial ecology to label transfer and use of materials and energy (Hauschild et al 2018, Wallsten 2015). In the socio-material flow methodology, the *actors* that enable and in other ways determine the flows are considered in addition. An actor can be an individual person, a company, or a non-governmental organisation (NGO), for example.

The following reasoning shows why the socio-material methodology not uses the concept of a *stakeholders* but a more inclusive view on actors. Stakeholders are popular to consider both in some social sciences (Freeman et al 2004) and in industrial ecology (Sonnemann and Margni 2015a) for identifying how, for example, a company can manage other actors that are clearly influencing the firm. The problem with the term stakeholder is that it is limited to considering that humans from the perspective of a company and not from the perspectives of the humans. Therefore, the socio-material flow methodology considers the *network* of *actions* performed by different actors and the resulting *processes* (events) over time.

Organisation is another established term for considering how groups of humans act (Robichaud and Cooren 2013). The term is used in the social sciences (Robichaud and Cooren 2013) and is applied to industrial ecology as well (Schiller et al 2014). An organisation is often seen as a unit that can be isolated from its surroundings and that has certain properties. The socio-material flow methodology, instead, focuses on how and why organisational processes create and maintain material flows. The methodology considers *interactions* throughout networks.

Table 1 presents an overview of the broadened vocabulary for material flow studies.

Table 1: A broadened vocabulary for material flow studies. Adapted from Paper V, page 8.

Currently prominent terms	Complementary concepts
Flow	Actor (any actor)
Stakeholder (primarily actors that companies wish to control)	Network Action Process (event)
Organisation	Interaction

The concepts for studying the influence of human actions on material flows can be further exemplified through an actual case on managing the tap water used in residential buildings (Baumann 2008). Figure 4a illustrates the focus of a *product life cycle* – the water flow and the technical devices. In Figure 4b, the *network* of *interactions* between *actors* is included as well. This reveals that several of the persons acting along the water flow were not well coordinated. Figure 4c also includes the *actions* were humans *interact* with the flow. It becomes clear that these determined the environmental performance. It is in this case relevant to understand both how these interactions occurred and how they were coordinated or not via organisational *processes* over time in a net of actors.

a

b

c

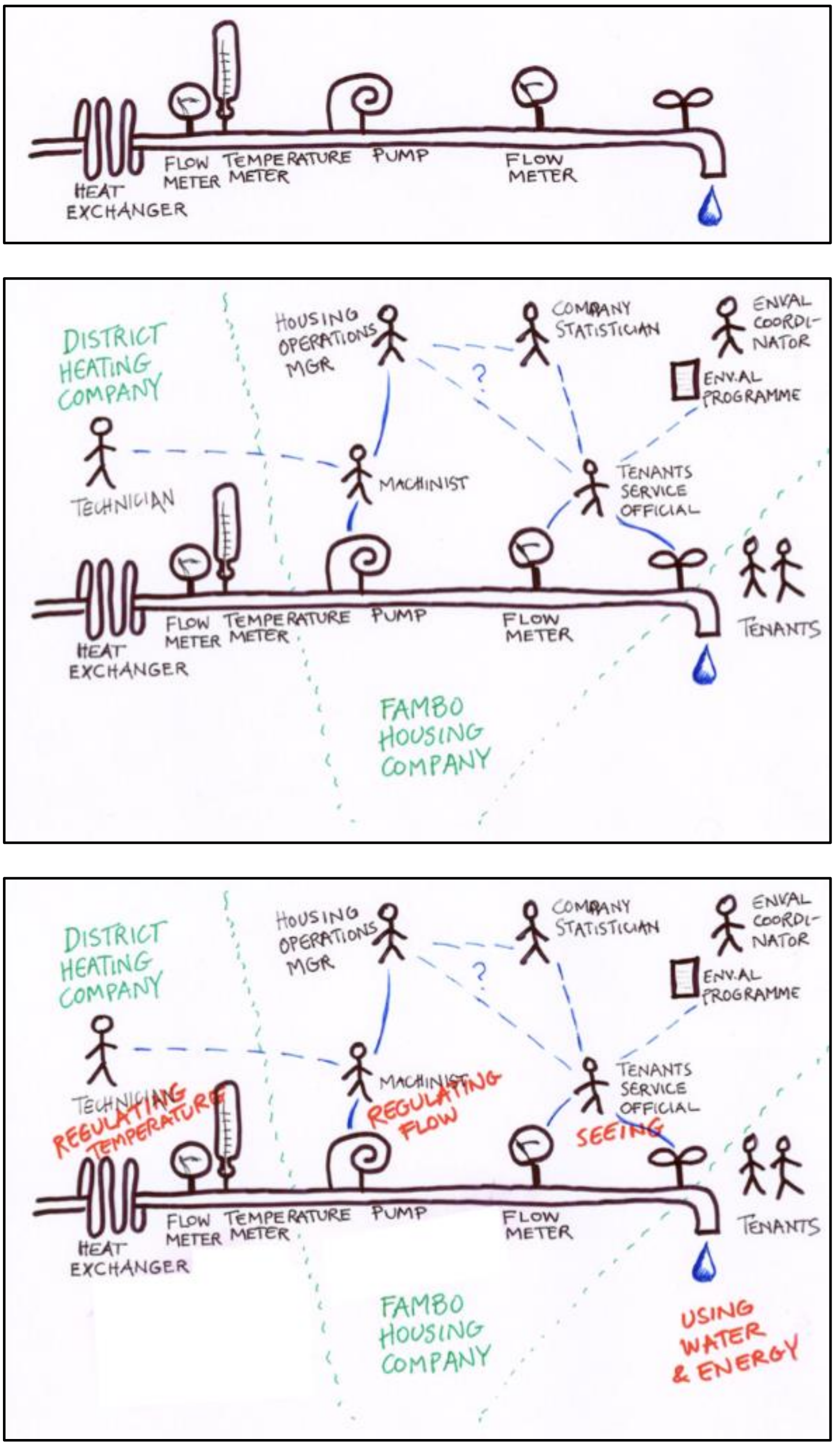

Figure 4: Illustration of why the study of networks of interactions between humans and between humans and material flows is useful for understanding environmental performance. From a case study on tap water supply and use in residential buildings. Source: Baumann (2008).

3 A combination of fundamentally different research perspectives

This chapter introduces the fundamentally different research perspectives that the socio-material methodology combines. The methodology and this dissertation follow a posthumanist (Barad 2003) ontology and epistemology that integrate the naturalistic, interpretative, and critical schools of philosophy of science (Braybrooke 2005). Ontology is about investigating how the world functions – “what it is for something to exist” (Craig 2005, p 756) – and epistemology is concerned with the nature of knowledge (Klein 2005). The deriving of the epistemology and ontology followed in the methodology is outlined in the following and is based on Paper V.

According to *naturalism*, as the term is used in contemporary philosophy of social science (Braybrooke 2005), the world consists of causal regularities that can be discovered. This is a major starting point for material flow studies, including life cycle assessment (LCA) (cf, Hauschild et al 2018) and material flow analysis (MFA) (Wallsten 2015), and for studies of the management of material flows, such as in agent-based modelling (cf, Deutz and Ioppolo 2015). The meaning used in this dissertation of the term naturalism aligns with the concepts *positivism* in the social and human sciences (Lincoln and Guba 1984), and *pre-modernism* and *modernism* in organisation studies (Hatch 2006).

Naturalistic descriptions of material flows and human actions, however, do not account for *interpretative* aspects: “the meaning of people’s actions, including their efforts to communicate and cooperate” (Braybrooke 2005, p 964). The interpretative approach has been used in an industrial ecology setting (cf, Newell and Cousins 2014). Newell and Cousins (2014) discussed how the interpretation and use of the term metabolism differed between different research areas. The authors showed that industrial ecology scholars used the concept as a representation of realistic material flows. As a contrast, they conclude that the field urban political ecology, which is based on geography and history studies, has used the concept “to destabilize binaries (e.g. nature–society, city–countryside) and unveil uneven power relationships shaping urban space” (Newell and Cousins 2014, p 711). The interpretative school is largely overlapping with a *social constructivist* and *symbolic* view (Hatch 2006), and with the social and human sciences terms *qualitative*, *subjective*, *ethnographic*, *phenomenological*, *hermeneutic*, and, confusingly, *naturalistic* (Lincoln and Guba 1984).

Scholars following the *critical* school take a further step (Braybrooke 2005). This school questions the interpretative school, because interpretations “may give untroubled pictures of societies in deep trouble, or picture the trouble in ways that serve the interests of the people who profit from it” (Braybrooke 2005, p 964). In industrial ecology, the mentioned study by Newell and Cousins (2014) followed a critical perspective in their way of treating different meanings of the urban metabolism concept in industrial ecology and other fields. Bras-Klapwijk (1999) has also used a critical perspective in industrial ecology, and suggest that quantitative LCA should be coupled with processes that acknowledge that no objective knowledge exists. The critical stance is closely related to *postmodernism* (Hatch 2006) and the *linguistic turn* in the social sciences and humanities (Barad 2003).

By combining naturalistic, interpretative, and critical approaches in a *posthumanist* ontology and epistemology, insights from all of these three approaches are taken into account simultaneously. A posthumanist material flow study accounts for several different aspects. Materials objects are seen as conditioned by both material flows and interactions with humans. How the flow is managed by a human is considered to depend on the meaning of the flow to this person. This meaning is viewed as having consequences for the equality between humans. Finally, the meaning and level of social equality are considered the outcome of interactions between humans and material objects. The term posthumanism is also largely overlapping with the concepts *new materialism* (Connolly 2013), the *material turn* (Bennett and Joyce 2010), the *ontological turn* (Escobar 2007), *flat alternatives* (Escobar 2007), and the *terrestrial turn* in philosophy of technology (Lemmens et al 2017). A posthumanist approach to material flows is supported by the three systematic as well as posthumanist approaches actor-network-theory (ANT) (e g, Latour 2005), object-oriented ontology (OOO) (e g, Harman 2011), and agential realism (e g, Barad 2007). ANT shows that society results from interactions between both humans and material objects (Latour 2005). OOO treats both humans and material objects as fundamentally similar in how they interact with each other (Harman 2011). Agential realism makes the statement that meaning and matter create each other and that we cannot understand them well if we consider them to be separate from each other (Barad 2007). Because of the systematic approaches of ANT, OOO, and agential realism, they align well with the systematic material flow studies in industrial ecology.

An important consequence of following a posthumanist ontology and epistemology is that the language of this dissertation intends to simultaneously reflect the merits of considering naturalism, interpretation, and a critical stance. The language has been chosen in order to be as readable as possible to persons that follow each of these three stances.

4 A research gap that a socio-material approach could fill

In this chapter, I reason about how the approach in the socio-material flow methodology differs from related research approaches. I have searched broadly for potential approaches that resemble the socio-material flow methodology, in order to, as far as possible, guarantee that such a methodology already has been created. The related approaches are found across many disciplinary fields, in engineering, natural science, social science, and interdisciplinarity between these.

4.1 Primarily engineering and natural science

A starting point for developing the socio-material flow methodology has been to target shortcomings of not explicitly considering how material flows are determined by humans. These shortcomings concern material flow studies such as material flow analysis (MFA) and attributional life cycle assessment (attributional LCA) (I find the related attributional LCA to belong to the interdisciplinary approaches that Sub-Chapter 4.3 covers).

In the general LCA approach, an environmental assessment is made of a material systems connected to a product's function (Hauschild et al 2018). These product system studies can be divided into the static attributional LCA and the dynamic consequential LCA (Hauschild et al 2018). Consequential LCA is a more recent distinction that in addition considers further effects, such as how increased use of biofuels affect the prices of agricultural products (Breetz 2017). In the general LCA approach, the systems typically cover entire product life cycle – from raw material extraction, via different industrial processes and use, to end-of-life treatment. The approach is advantageous because it principally covers as many as feasible of the environmentally important organisations and other actors along the life cycle. The general LCA approach can thereby enable actors to avoid sub-optimisation within the product life cycle. In addition, the general LCA approach does not cover only one type of environmental impacts, which can facilitate avoiding burden shifting between, for example, climate impacts and biodiversity impacts. The outcome is a comparison of environmental performance between different product life cycles or between different technical processes along such a cycle. An LCA practitioner will probably have a good overview of how different actors influence the product life cycle but the LCA methodology does not require or guide documentation of this knowledge.

Practical aspects of behaviour and preferences, however, are reasonable to consider when an attributional LCA study has generated an array of different technical options and their feasibility is evaluated. An evaluation of alternatives for decreased bread discarding in a Norwegian attributional LCA led to the identification that retail shops usually had agreements with bakeries on take-back of unsold bread and, therefore, had little motivation to reduce the waste bread (Svanes et al 2019).

The performing of an attributional LCA may also be one of the steps in a procedure, such as eco-design in order to develop environmentally more efficient products (Kurczewski and Lewandowska 2010). The preferences and choices of actors and the feasibility to sell a product are then human-oriented aspects that naturally become important. The socio-material flow methodology specifically focuses on any environmentally relevant relations between humans that affect material flows.

The material flows are covered to a further extent in organisational LCA than in standard LCA. Organisational LCA considers the environmental performance of all product life cycles that are directly controlled by a company or other larger organisational unit (UNEP 2015). The term organisation is in the approach used for upscaling attributional LCA to a strategic decision-making level and confining it to strategic decisions and to one organisation's perspective. Organisational LCA facilitates avoiding sub-optimisation within a company, but the organisational process complexity that is at the core of the socio-material flow methodology is not in focus.

MFA is similar to LCA in focusing on technical processes and material flows. An MFA typically covers the flows of one material within, to, and from a country, or globally, and without explicit consideration of different types of environmental impacts (cf, Brunner and Rechberger 2017).

Life cycle management (LCM) (Sonnemann and Margni 2015a) is closely related to LCA. LCM is used as a term for approaches built on LCA and LCA-based perspectives and designed for business actors (e g, Sonnemann and Margni 2015a). LCM has been presented as being "about making life cycle thinking and product sustainability operational for businesses that are aiming for continuous improvement" (UNEP/SETAC 2015). The LCM literature has primarily resulted in general suggestions on how LCM ought to be performed (Nilsson-Lindén et al 2018). This gives only a limited aid to understanding of the complicated organisational processes within and between, for example, companies along product life cycles. LCM this far has not focused on how management is related to the actual actions performed by blue collars and other humans handling the material flows. The socio-material methodology provides a tool because it allows for the tracing of actions that influence the material flow. In general, the scale of resolution distinguishes the socio-material flow methodology from LCM. Figure 5 illustrates the difference in focus, and zooms in from, for example, whole product life cycles in the left end of the figure to single actions in the right end of the figure. LCM is typically concerned with whole product life cycles or whole companies, in contrast to the consideration also of specific actions in socio-material flow methodology.

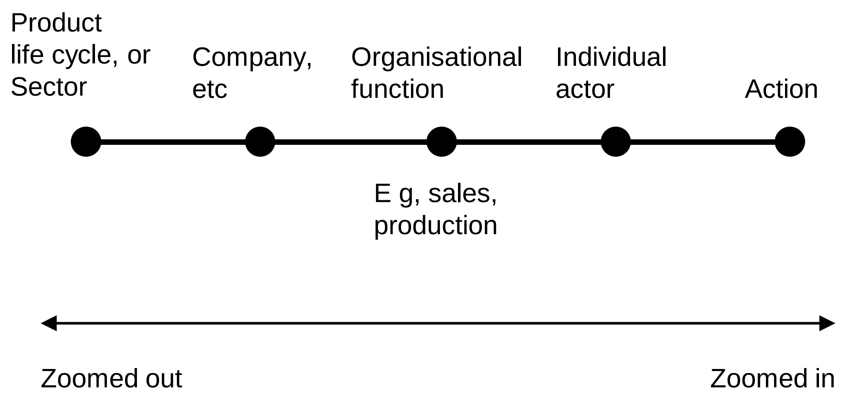

Figure 5: Different scales of resolution between a zoomed out view of a product life cycle or an industry sector (left) and zoomed in view of a single action (right).

Some LCA studies have incorporated an actor’s perspective (henceforth LCA of actors) (e g, Berlin et al’s 2008). An LCA of actors focuses on the quantitative product life cycle environmental potentials from certain choses made by certain actors. The approach has been used by Berlin et al (2008) in study on dairy products and in a Löfgren et al (2011) study of a manufacturing industry. Berlin et al considered options for different actors to reduce losses, use organic labelling, change transport patterns, and influence energy efficiency. Löfgren et al calculated only the product life cycle impacts that the manufacturing firm directly could influence – the impacts of the firm’s scrapping of components, removing of materials, and electricity use. The studies on LCA of actors treated the actors as rational and from one another independent actors, contrary to the focus in the socio-material flow methodology on the relations between the actors and between them and other actors.

Research on relations between the detailed flows in production processes and product life cycle environmental performance has also targeted options for more specific actors than the general LCA approach does (e g, Berlin et al 2007). Berlin et al (2007) provided a method that an actor can use to find a sequence of the production of different types of dairy products that can lower the amount of waste from the production. The method was shaped by characteristics of the production processes of the different products. Similarly, in an approach put forward by Despeisse et al (2012), different actors are targeted in a model on material links between different units and technical processes at the factory level and the product life cycle environmental performance. By pointing out specific functions where, for example, optimisation of the production schedule could have an effect on environmental performance, it is easier for the involved actors at the factory to be identified and for them to understand their environmental roles.

The environmental performance of the product life cycle is the starting point in a simplified tool for reaching from identification to realisation of product specific circular economy options (Jørgensen and Remmen 2018). The options are sought via practical considerations, such as motivating consumers by providing discounts upon returning old products, and, therefore, focus on both actors and actions of relevance for the realisation of changes to the product life cycles.

Several attempts have, thus, been made to better include the importance of actors for the environmental performance of a product life cycle, but none of them presents a systematic and theoretically grounded methodology. In relation to this observation, Boons et al (2012) have arrived at a list of five aspects that need specifically to be considered for sustainability of product life cycles, including how sustainable practices are diffused and who drives the sustainability agenda. The socio-material flow methodology has been developed as a means for gaining insights on such phenomena.

4.2 Primarily social science

Material flows have also been related to in social science based studies. These cover interpretations of LCM, referred to as life cycle thinking by Nilsson-Lindén et al (2018), interface actors (Wallin 2014), supply chain management (SCM) (Ansari and Kant 2017), commodity chains (Koponen 2009), and management and organisation (e g, Molina-Azorín and López-Gamero 2014).

LCM interpretations have been studied among engineers. Research on interpreting LCM has been carried out on LCA practice in two companies in the Swedish forest product industry (Rex and Baumann 2008). The findings show that unexpected events and the preferences of individuals largely influence the practice, and thereby cover the specific actions but not the quantitative environmental performance considered in the socio-material flow methodology. Other research on the same theme has considered organisational factors from the perspective of individual engineers (Löfgren 2012). The organisational findings in the studies on LCM interpretations focus on actors rather than the different actions performed by each of them; focus on specific generalised factors of organisation, such as organisational infrastructure, rather than a diversity of actions; and do not explicitly relate to environmental performance. The research, therefore, differs from the socio-material flow methodology by not focusing on the specific actions that determine the material flows (see also Figure 5).

Research has also focused on interface-actors (Wallin 2014). Interface-actors are defined as actors that have “a near exclusive ability to directly and physically influence specific pressures on the ecosystem” (Wallin 2014, p 7). These actors have been considered in research on small-scale sewage treatment and related actors in Sweden (Wallin 2014). The interface-actors’ perceptions and motivational factors regarding hypothetical future changes of sewage systems and potential policies on them were studied. Although the mediators directly at the material systems are highlighted, the more detailed level of each action, covered in the socio-material flow methodology, is not the prime analysis level (see also Figure 5). In addition, the focus lies on perceptions and motivational factors while not considering environmentally impacting actions as such.

A supply chain overlaps with the material flow in a product life cycle. Supply chains are studied in SCM – “the task of integrating organizational units along a supply chain and coordinating material, information and financial flows in order to fulfill (ultimate) customer demands with the aim of improving the competitiveness of a supply chain as a whole” (Stadtler 2015, p 5) – and environmental supply chain governance (Bush et al 2015). Sustainability aspects of these chains have been studied in SCM (Seuring 2004). A range of different theoretical perspectives has been applied, including complexity theory and institutional theory. The studies are, however, limited, because they, contrary to the socio-material flow methodology, use the perspective of one company (Nilsson-Lindén et al 2018) instead of a taken-together consideration of different actors along a material flow and focus on the supply to the studied company. Beyond the single company, supply chain governance studies have focused on presenting lists of environmentally relevant social aspects that include dialog and context-sensitivity to supply chain governance (Boström et al 2015), and distinguishing between a focus on realising change in parts of, along, or via supply chains (Bush et al 2015). The supply chain governance literature points out relevant nuances of governance but does not focus on the tracing of links of actions in focus in the socio-material flow methodology.

Commodity chains have also been related to in the industrial ecology context by Koponen (2009). The concept is considered to facilitate connecting the physical and social worlds by “understanding the various ways human actors work creating stable and efficient (and unstable and repressive) production cycles and technical capabilities” (Koponen 2009, p 197) in relation to global flows of goods. The approach seems to be more focused on but also limited to power as problematic and an aggregated level of analysis than the socio-material flow methodology.

Environmentally oriented studies of sociology (Lidskog et al 2016), and of management and organisation (Kallio and Nordberg 2006) have become academic sub-field on their own. Environmental management and organisation research has been described as formed heavily by its parent fields: management science and organisation studies. Relations between human actions and environmental performance have only been considered to a limited extent (cf, e g, Molina-Azorín and López-Gamero 2014). The studies have typically covered one or a few proxies of environmental performance, such as the recycling rate. Environmental management studies have been characterised as focusing on the aspect of whether environmental impacts are accurately reflected in environmental perceptions and attitudes, and interpersonal relationships, rather than addressing environmental impacts as such (cf Boons 2013). This limited consideration of the natural environment is found in industrial ecology related management and organisation research on intricate relations conditioning industrial ecology implementation (Cohen-Rosenthal 2000) and detailed studies of how everyday interactions of on beforehand pro-environmentally labelled behaviour (Nye and Hargreaves 2010). To these behavioural and implementation focused studies, the socio-material flow methodology provides a complement through the consideration of material flows passing many different actors, and by the focus on the socio-material interaction points that illustrate the inseparability of material and human aspects.

Compared to the different social science approaches to humans and material flows, the socio-material flow methodology more clearly bases the study of humans on the flows, through which environmental impacts occur, and connects different points of interaction along these flows.

4.3 Interdisciplinarity between the social and material domains

Some interdisciplinary types of study that combine social science and research on environmental performance have also been found: mapping systems and networks (e g, Romero and Ruiz 2014) (also discussed in Papers II and V), other industrial ecology (e g, Wallsten and Krook 2016), and beyond industrial ecology (e g, McGinnis and Ostrom 2014).

Mapping of systems and networks has applied a limited number of characteristics of how humans act in relation to material flows (cf, e g, Romero and Ruiz 2014).

One sub-set is studies on quantitative actor models (e g, Zamagni et al 2012). Studies on models have become established in the agent-based modelling (Romero and Ruiz 2014), consequential LCA on environmental impacts via price effects of product life cycle changes (Zamagni et al 2012), scenario-based LCA (Miller and Keoleian 2015), and social impacts from (rather than on) product life cycles in social LCA (Garrido et al 2018). Additional modelling research covers economic and psychology systems modelling coupled with MFA (Binder 2007), actors and activities in product/service systems (Desai et al 2017), consideration of actors at different system levels in different institutional settings, and intermediaries in sustainable transitions (Fischer and Newig 2016), and fuzzy cognitive modelling for a regional system (Penn et al 2013).

Another systems and network sub-set is research on social embeddedness, which has resulted in finding among other that both explicit and tacit transfer of knowledge exist in industrial symbiosis networks (Schiller et al 2014). Networks are also considered in the sub-set political industrial ecology, where the uneven contribution from different actors to adverse effects from product life cycles have been studied (Newell and Cousins 2014).

Industrial ecology more generally has been considered in relation to social science through a sub-set on lists of social aspects, regarding informing material flow studies by established environmental social science (Hoffman 2003) and established topics such as management (Korhonen et al 2004), and regarding multi-goal strategies, process innovation, and other social aspects derived from industrial ecology themes (Vermeulen 2006). A study on mapping systems and networks can typically be used to simulate the effect of certain combinations of actors in the future. On the other hand, such a type of study puts less focus than the socio-material flow methodology on the details of how and why a certain environmental impact occurs. Besides the rational approaches, and political approaches in political industrial ecology, dominating this research, Kezar (2001) points out that organisational change has been considered to occur through the following: negotiation, adaption, natural progression, changing the culture, and replacing the frame of mind when needed. The posthumanist starting point is used in the socio-material flow methodology in order to enable the consideration of these and other approaches.

A posthumanist perspective, however, is to a certain degree present in industrial ecology studies that are hybrid (e g, Fischer-Kowalski and Steinberger 2011) (see also Paper V) and in studies on the intricate interplay between humans and material objects that the matters of concern concept captures (e g, Lazarevic 2018) (Sub-Chapter 7.2 explains the concept further). The hybrid research includes conceptualisation of how environment impacts via, for example, resource scarcity and hurricanes influence human actions (Boons 2013), a call for considering local-global connections and population size (Fischer-Kowalski and Steinberger 2011), and reasoning on how generalised energy efficiency calculations do not account for the desires of citizens for the comforts provided by heating (Shove 2018). Other matters of concern related studies, in an industrial ecology setting, have also been performed. The results cover suggestions for policy makers in relation to LCA studies to stimulate different actors to state their values (Bras-Klapwijk 1999), explanations for a plastics controversy in terms of different incompatible framings (Tukker 1999), and how the same disconnected infrastructure was part of 'realities' that differed between different actors (Wallsten and Krook 2016). The socio-material flow methodology belong to the same type of research as these hybrid and matters of concern related studies, and could complement this research by providing a more general and held together approach that explicitly considers the chains of connections in material flows and nets of human actions.

Beyond industrial ecology, the relations between actors and the natural environment are covered in social-ecological systems studies (e g, McGinnis and Ostrom 2014) and in environmental science and technology studies (e g, Landström et al 2019). Environmental science and technology studies focus on the roles that science and technology related to environmental issues can play for humans. Landström et al (2019) have studied how laypersons can interact with computer modelling and related experts on an issue of flood risk management. This puts emphasis on the important links between humans and technical and scientific artefacts within human-environment relation. Social-ecological systems studies have been described as nested systems that link multiple types of governance to natural resources use (McGinnis and Ostrom 2014). One main topic of discussion seems to be whether the SES approach is useful for studying aspects that are additional to direct human handling of ecological systems in, for example, subsistence farming. SES studies are, therefore, not focused on relating human actions to natural resource use via the man-made technical processes that play vital roles in today's society and that are considered explicitly in the socio-material flow methodology through LCA and MFA.

4.4 Overview of the research approaches that relate to the socio-material methodology

The long list of research related to the socio-material flow methodology is not complete and could be reasoned about in more depth. The listed research, however, shows that the socio-material methodology can fill research gaps when it comes to practical description of the links between actors, actions, technology, flows, and environmental impacts. Table 2 presents an overview of the outlined research that relates to the socio-material flow methodology.

Table 2: To the socio-material flow methodology related research on environmental performance and management.

Research domain	Fields, sub-fields, and approaches (references are given for less established concepts)
Primarily engineering and natural science	Modelling material flows: - Attributional life cycle assessment (attributional LCA) (e g, Kurczewski and Lewandowska 2010, Svanes et al 2019) (I list consequential LCA later in the table) - Organisational LCA - Material flow analysis (MFA) Other: - Life cycle management (LCM) - LCA of actors (Berlin et al 2008, Löfgren et al 2011) - Relations between specific production processes and product life cycles (Berlin et al 2007, Despeisse et al 2012) - Realising product circular economy options (Jørgensen and Remmen 2018)
Primarily social science	Industrial ecology: - Interpreting LCM (Löfgren 2012, Rex and Baumann 2008) - Interface-actors (Wallin 2014) Other: - Supply chain management (SCM) and supply chain governance (e g, Boström et al 2014, Bush et al 2015) - Commodity chains - Management, organisation and sociology studies (e g, Cohen-Rosenthal 2000, Nye and Hargreaves 2010)

Interdisciplinarity between social science, engineering, and natural science	Mapping systems and networks:
	- Quantitative actor models:
	  - Agent-based modelling
	  - Consequential LCA
	  - Scenario-based LCA
	  - Social LCA
	  - Other approaches (e g, Binder 2007, Fischer and Newig 2016)
	- Embeddedness (Schiller et al 2014)
	- Political industrial ecology / spatially-explicit LCA
	- Lists of social aspects (Hoffman 2003, Korhonen et al 2004, Vermeulen 2006)
	
	Other industrial ecology:
	- *Hybridisation* (Boons 2013, Fischer-Kowalski and Steinberger 2011, Good and Thorpe 2019, Shove 2018)
	- Other *matters of concern* (Bras-Klapwijk 1999, Freidberg 2018, Lazarevic 2018, Tukker 1999, Wallsten and Krook 2016)
	
	Beyond industrial ecology:
	Environmental science and technology studies (e g, Landström et al 2019)
	Social-ecological systems

5 Research journey

In this chapter, I make some reflections on my research journey through the doctoral project that this dissertation is based on. I cover a chronological account of the five papers included in the dissertation (this account does not follow the order of the numbering from I to V of the papers), major challenges along the path, and different structured forms of partaking in a research context.

5.1 A chronological account

The actual work that led to Papers I–V is based on the state at that time of the research on the socio-material flow methodology. As a result, the work on the different papers overlapped.

The initial part of the doctoral project included the work on the screening variant of the methodology introduced in Paper III. At this time (2008), two different approaches to the socio-material flow methodology had been tested. These approaches are the life cycle nodal organisation (LCNO) focus on the organising at one node in a product life cycle and an *actor life cycle assessment* (actor LCA) (Brunklaus et al 2010) approach that combined thorough LCA studies with analysis of the choices made by and cooperation between actors along the product life cycles. LCNO case studies on housing management had resulted in findings on the environmental advantage of coordinating renovation with energy saving measures (Brunklaus 2009). Methodologically, however, Brunklaus (2008) concluded that the application of the LCNO approach required that the analyst invested a large amount of time into the study. The actor LCA case study on passive houses revealed a lack of focus on residents' choice of energy in passive houses despite the environmental importance of this energy supply (Brunklaus et al 2010). Methodologically, Brunklaus (2008) did not identify any apparent shortcomings of the actor LCA approach. The environmental relevance of the complex organising identified in the LCNO study, however, led to designing the study leading to Paper III on exploring the possibilities of using a screening LCNO approach. In addition, at the time, the socio-material flow methodology had only been used in studies on material flows through residential buildings (e g, Brunklaus 2009) and commercial buildings (Lundberg 2008). Consequently, the testing of the screening on five other types of services and products – bowling, bread, coach services, concrete, and road management – was useful for further testing the methodology.

The case studies also made it possible for me quickly to get an understanding of the practical opportunities for and limitations to case studies of the organising of material flows. It can be useful to be familiar with carrying out case studies before performing a literature review and a conceptualisation of field research.

The literature review presented in Paper II was launched in 2009. The field studies had given me insights into the aspects involved in combining material flow studies and organisational studies, and I could assess other literature as someone with experience comparable to the experience of the authors of this literature. Paper II is the result of several different reviews and review attempts. The first idea was to cover studies on the topic of organising around flows in industrial ecology literature. This was found to be difficult because of the problems of choosing keywords and search terms (Lindkvist and Baumann 2014). The results were very general and, among other, showed that in a random sample of 200 articles were limited to naturalistic ontologies and epistemologies. To get a more focused picture of the research related to material flows that most prominently try to combine social science studies of how humans act and quantitative material flow studies, different starting points were sought in the posthumanist literature. Eventually, the consideration by Latour (2004) of matters of concern rather than matters of fact was found to align with a limited number of studies found through a snowballing technique and, therefore, the literature study followed this analysis approach (see Paper II).

The biannual conference on life cycle management (LCM) provided an opportunity in 2011 for the presentation of findings on different specific actors' possibilities to influence the environmental performance of product life cycles (Paper I). The paper covers Brunklaus et al's (2010) actor LCA case study on the management of material flows that relate to residential buildings. Additionally, the overview includes publications that do not directly follow the socio-material flow methodology: an example of decision-maker analysis in LCA (Ekdahl 2001), on a study of the influence from actors at this company's production processes (Löfgren 2009), and one on actors' influence on the dairy chain (Berlin et al 2008).

In 2012, work began on the testing of the socio-material flow methodology in a recycling context (Paper IV). The at the time novel product chain organisation (PCO) approach for describing the organisation along longer parts of a product life cycle was used. A case study was performed on metal packaging (presented in Paper IV), which complemented previous PCO studies on batteries in electrical vehicles (Eriksson and Olsson 2011), chocolate (Borg and Selmer 2012), and nappies (Gullbring et al 2010). The use of the PCO variant together with the screening LCNO based study provided me with more perspectives on how socio-materiality could be applied.

The study leading to the conceptual Paper V was also designed in 2012. The study on concepts was motivated by the considerable number of case studies already performed using the socio-material flow methodology, on: residential buildings (Brunklaus 2009); commercial buildings (Lundberg 2008); nappies (Gullbring et al 2010); batteries in electrical vehicles (Eriksson and Olsson 2011); bowling, bread, coach services, concrete, and road management (Lindkvist and Baumann 2010); and food in general (Brunklaus 2011). The focus on concepts was also warranted by the development of a fragmented terminology on socio-material interaction in studies on the methodology (e g, Lindkvist and Baumann 2010), and having discovered links between the methodology and posthumanist studies by Harman (2011) and Barad (2007). Within my doctoral project, the conceptual work helped systematise the description of methods employed in already conducted studies: the literature review (Paper II) and the case studies with practical methodology development (Papers III and IV). The method in the study reported in Paper V consisted of analysing and synthesising studies on the socio-material flow methodology, social science literature for outlining a broadened vocabulary on material flows, literature on ontology and epistemology, and the three posthumanist approaches actor-network-theory (ANT), object-oriented ontology (OOO) and agential realism.

5.2 Major challenges

The studies and writing that Papers I–V are based on have been challenging to me regarding communication between research disciplines. This has both provided insights and required a handling of these challenges.

Communication between considerably different academic disciplines appeared early on in my studies to be vital. My project has covered very different approaches, such as naturalism and the critical social science school, and quantitative engineering presented in tables and the stories that scholars in the humanities seem to value highly. If I would like seriously to let these perspectives, which all seem to have a considerable relevance, inform each other, I would need to both create an interest from and avoid misunderstanding when communicating with researchers aligned with each of the perspectives. This involves relating to the different logics and ways of being systematic that are part of the different perspectives.

My approach to this issue has grown out of experience, which includes advice from others. I have tried to listen, read and write with a very open mind, to try to see the research processes, and to figure out how we could be of academic interest for each other.

The most prominent reflection on this process is that it is possible but takes time, and may result in unexpected outcomes. That it takes time might result from that interdisciplinary research between very different disciplines has only been to a limited extent performed recently. It is potentially important for considering the difficulty of combining fundamentally different approaches when evaluating interdisciplinary research.

Thus, the socio-material flow methodology may provide a more environmentally effective approach than other industrial ecology-based methods but may require some additional effort to develop.

5.3 Partaking in a research context

The discovery and handling of many of the challenges of producing Papers I–V are related to furthering an already launched methodology and my partaking in research programmes, groups and courses.

My doctoral research was largely a furthering of the environmental assessment of organising (EAO) approach. EAO as well as this dissertation combine naturalistic material flow studies with posthumanist organisational studies. This continuity provided both a security, because the methodology already had passed the test stage, and direction, due to the starting points provided by publications on EAO studies regarding which other research to consider, how to perform case studies, and which concepts to develop (e g, Brunklaus 2008).

The research programme Organising for the Environment (OrM) provided additional support already from the beginning of my doctoral project. In OrM, research topics about connections between organisational aspects and the natural environment were studied, discussed, and explored by its six participants. This involved researchers on the socio-material flow methodology and social scientists researching environmental aspects through economic history and organisation studies. A seminar series was the primary arena. We both discussed to each participant's research relevant texts from, for example, environmental sociology and science and technology studies and presented our own research to each other. This was primarily occurring at an early stage of my doctoral project, and gave me a jumpstart for understanding researchers with different academic backgrounds. The small size of the group and the meeting with the same participants regularly made it possible to get a deeper understanding for the different academic interests in the other researchers' fields. OrM also provided funding, and, therefore, the participant Petra Adolfsson, from the perspective of organisation studies, could assist me with feedback beyond the discussions in the seminar series.

Additional helpful fora have been the Organizing Sustainable Consumption and Production (OSCP) section of the International Society for Industrial Ecology (ISIE) (primarily in 2012), the seminar group on organisation and management of material flows (OMMF) (since 2015) and doctoral courses.

The fora have provided parallel and continued provision of reflection on my research role in academia more broadly. The courses include engineering based subjects at Chalmers University of Technology (Environmental and energy systems analysis: roots and branches, 7.5 ECTS, 2010). Qualitative social science was covered in sociology (Sociology of knowledge and theory of science, 7.5 ECTS, Gothenburg University, 2009) and organisation studies (Actor-network theory and organising, 7.5 ECTS, Gothenburg University, 2009). In addition, perspectives were gained from the posthumanities in general (Materiality, thing theories and material cultures, 10 ECTS, Gothenburg University, 2012–2013) and through the environmental humanities (2 ECTS, University of New South Wales, 2016).

The doctoral courses provided slightly different interaction from the OrM and OMMF seminars because almost all participants were doctoral students. They were my peers and thereby I could easier become more personally acquainted with them, which seemed to allow for a deeper understanding of what motivated them to perform their research. Further, their perspectives appeared to be different from more senior researchers'; both less tightly dependent on earlier research approaches because the seniors were keepers and representatives of certain research approaches, and more limited due to the doctoral students' limited experience of deeper interaction with a broader spectrum of researchers and research.

6 A socio-material perspective on material flows

In this chapter, I give a stepwise presentation of the developed socio-material flow methodology for a combined understanding of material flows and the organisational processes that determine them. The methodology is a central outcome of my doctoral project and around fifteen years of studies by the research group that my project has been performed in (Baumann et al 2015). The presentation of the methodology includes the steps aim, concepts, procedures, and methodology variants. The structure of the chapter is based on Paper V.

6.1 Aim

The socio-material flow methodology aims to be applied for assisting actors such as managers, policymakers, and non-governmental organisations (NGOs) in performing environmentally effective actions.

6.2 Concepts

Seven concepts in the socio-material flow methodology give an overview of the technical and organisational processes that application of the methodology can explain. The concepts cover types of studies in the methodology, further concepts that intend to capture the central aspects of the types of studies, and two conceptualisations on limitations in organisational processes. The concepts are:

Types of studies in the socio-material flow methodology:

- *Material flow studies*
- *Studies of action nets* (the relation to the term network is explained further on in the sub-chapter) for exploration of organisational processes

Concepts for describing key feature, ingredient, and component in a socio-material study:

- *Man-made flow*, for material flow studies
- *Socio-material interaction point* (SMIP), for the combination of a material flow study and a study of action nets
- *Action net*

Concepts for analysing limitations in the action net and its alternatives:

- *Limited connection*
- *Incompatibility between alternatives*

The following text describes the seven concepts in greater detail. Figure 6 illustrates the five concepts for so-ma description,

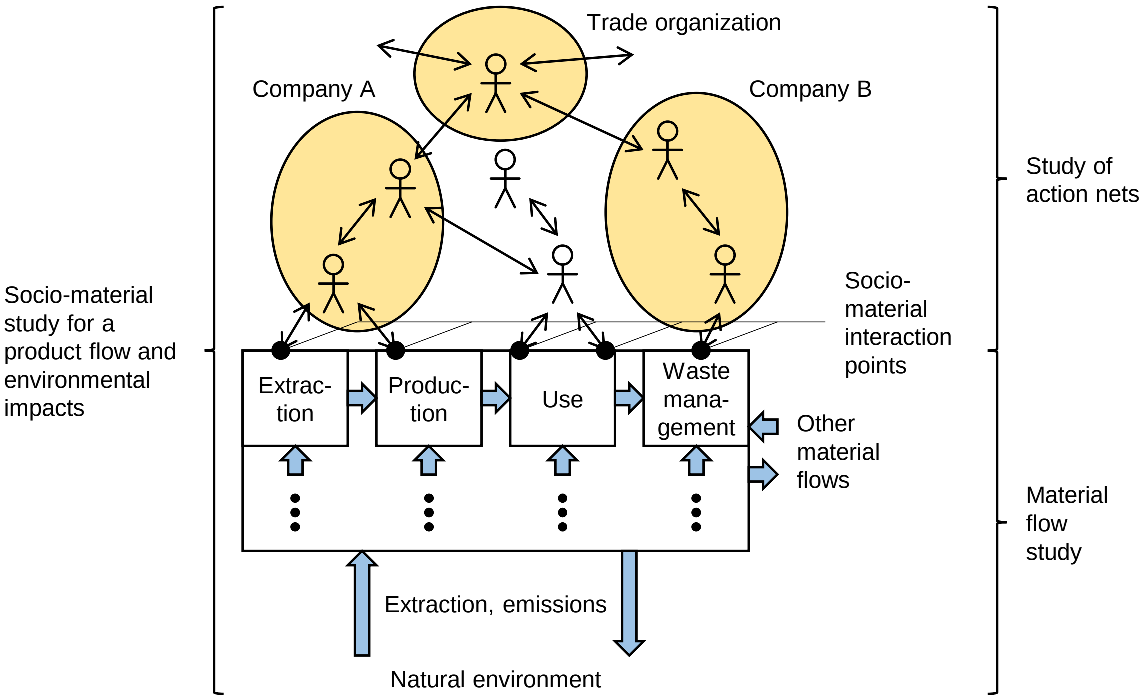

Figure 6: An introduction to core concepts in the socio-material flow methodology. The illustration is based on a hypothetical product life cycle. Other environmentally important technical and organisational major processes can be retail and transports. Source: Paper V, page 13.

Man-made flow

The starting point of the socio-material flow methodology is to consider material flows created by humans – *man-made flows*. A man-made flow is often not limited to one company or other actor, but can be handled by many actors at different locations. A flow at one technical process can depend on how the flow is managed at other technical processes; for example, the baking of a loaf of bread usually requires the cultivation of grain and the use of recycled steel in one product depends on the amount of scrap steel collected. For practical reasons, a man-made flow can only either be considered a limited number of steps away from a starting point or be studied at a limited level of detail. Without humans, however, the man-made flow would cease to exist.

In the methodology, a *material flow study* is used to map the man-made flows. The material flow study can be based on different tools, and life cycle assessment (LCA) (e g, Hauschild et al 2018) and material flow analysis (MFA) (e g, Brunner and Rechberger 2017) are suggested as starting points.

LCA highlights that the function that a product provides to a user (such as heating 1 m^3 of indoor air to a specified temperature) depends on often longs chains of man-made flows. The flows can reach from raw material extraction in, for example, ore mines to retrieve the substances that technical processes turn into a product, to waste management and potential subsequent use in other products. LCA studies also cover more than one type of environmental impacts. These impacts categories can include global warming, decreased diversity of species, and mineral resource scarcity. The results from an LCA study are typically quantitative figures of the flows and estimated environmental impacts.

MFA can be used quantitatively to model the main flows of one material or a few materials, such as concrete within and to and from a country, and a group of metals globally (e g, Brunner and Rechberger 2017). Such studies can reveal the potential accumulation in, for example, buildings of an environmentally impacting material, and amounts of materials theoretically available for recycling.

Socio-material interaction points

In order to reach a held together understanding of man-made flows, their environmental impacts, and the organisational processes that determine the flows, the socio-material flow methodology conceptualises the connections between the man-made flows and the organisation of them (cf, Baumann 2008). Studies on the methodology have shown that managers and policy-makers often do not beforehand have an environmentally sufficient understanding of how blue-collar workers and product users ultimately determine environmental performance by interacting with the flows (e g, Paper IV).

The methodology uses the concept *socio-material interaction point* (SMIP) (Baumann 2008). It refers to “the points where human actions come the closest to [man-made flows]” (Paper III, p 462). The environmentally relevant interactions occur, for example, when a blue-collar worker turns a switch that adjusts a setting in a production plant and a customer looks at a product in order to determine whether to purchase it or not. A SMIP, thus, is an interaction between the material domain of man-made flows and the social domain of organisational processes.

Several terms are used in research to designate the consideration of both social and different material aspects. Prominent terms are *socio-material* (e g, Åsberg et al 2012), *sociotechnical* (e g, Bijker et al 2012), *socio-ecological* (e g, McGinnis and Ostrom 2014) and *hybrid* (e g, Callon 2001). The term *socio-material* is used in order to include all types of materiality as well as clearly to show that both the material dimension and the social dimension are covered. The term sociotechnical has been used to focus on the materiality present in technology, while not specifically covering environmental impacts because these are beyond the 'technical' (e g, Bijker et al 2012). Similarly, the term socio-ecological puts focus mainly on one type of materiality – the ecological – but only to a limited extent considers the currently central role that technical processes play (e g, McGinnis and Ostrom 2014). Finally, hybrid is a useful term to denote that something is just not the addition of two parts but an inseparable unit (e g, Callon 2001). Referring to hybridity, however, does not explicitly reveal the type of hybridity, and does, therefore, not point out to an engineer or social scientist that both their own domain and another domain are covered. The term socio-material can be seen, on the other hand, as downplaying this hybrid view. Because of the clarity of the term socio-material, however, I still find its usefulness to exceed that of the term hybrid.

The word *interaction* in the SMIP term is used to show that a human can influence a material object, and vice versa. The latter is the case when a piece of bread is discarded instead of consumed because of the age of the bread.

Finally, the *points* are considered in the SMIP concept to highlight that the organisational processes that determine a man-made flow usually occur at more than one interaction point along the flow. Interaction at one point can also involve more than one organisation, which is the case when a supplier delivers a product to a buyer.

Organisational processes: action nets

Action nets (Czarniawska 2004, 2008) are included in the socio-material flow methodology in order to enable an understanding of how the different interactions at the SMIPs are determined by different organisational processes. Action nets are used in the methodology to trace connections from management and policy-making to the SMIPs where the man-made flows are created and conditioned, via middle managers and foremen within an organisation and the connections between a company and its suppliers and environmentalist NGOs. Thereby, the many links from a top management decision to an environmentally relevant action at a man-made flow and environmentally relevant organisational challenges are considered. In order further to put focus on actual events rather than the structure of actors, the action net is concerned with organisational processes rather than the actors that the processes involve (because LCA is concerned with technical processes, a process focus provides a logical bridge between the two types of study). In addition, more than humans are usually studied; computers, documents, buildings, infrastructure, and other material objects play roles in how actors interact with each other.

The term *net* is similar to the term network, but a "network assumes actors who [connect to each other], whereas action nets assume that connections between actions produce actors" (Czarniawska 2004, p 781). No actor exists prior to actions.

A *study of action nets* is intended for creating descriptive results from qualitative studies of organisational processes.

Action nets are to a considerable extent based on the method actor-network-theory (ANT), which has become established in social science studies of how science is performed and how technology created (Czarniawska 2005). ANT has also been referred to as sociology of translation (Callon 1986) and the social shaping of technology (Jørgensen et al 2009) and which is closely related to social construction of technology studies (Bijker et al 2012). ANT has grown out of studies of how science and technology is created through interactions between humans and material objects in, for example, laboratories (Latour 1987). When using ANT-based approaches, it is relevant to consider that scholars have pointed out that ANT studies can lead to presenting nets and networks that may be obvious in hindsight but are difficult to identify before they have been established (Collins 1992).

Additional concepts on organisational limitations

The concepts limited connection (between different actors and other objects) and incompatibility between alternatives are used in the methodology to highlight limitations in organisational processes. *Limited connection* is a concept designed to capture that different objects, such as two persons whose interactions influence the environmental performance, may not know the effect of each other's actions well (cf, Harman 2011). The approach object-oriented ontology (OOO) (e g, Harman 2011) inspired this concept. *Incompatibility between alternatives* refers to that some alternatives, such as carrying out an activity in-house and procuring it, cannot both be performed simultaneously (cf, Barad 2007). Each alternative may have its environmental advantages and disadvantages, and, therefore, an incompatibility between the alternatives can limit the environmental optimisation that can be reached. The concept is based on Barad's (2007) agential realism.

6.3 Procedure

The use of the socio-material flow methodology in practice is based on a sequence that has been established through different case studies that have followed the methodology (source: Paper V, p 17):

1 Describe the man-made flows.
2 Identify the socio-material interaction points (SMIPs).
3 Trace and describe action nets (which can include chains of many actors within and between organisations) between the SMIPs.
4 Compose an overview – by merging the descriptions from steps 1–3.
5 Analyse how the man-made flows are affected by the different actions in the action nets.

Step 1 typically consists of a material flow study. The use in practice of a material flow study in a socio-material flow study can be exemplified by outlining the application of LCA. An application of the socio-material flow methodology can include actual an LCA study or a compilation of already presented LCA results. If an actual LCA is performed as part of the application, a thorough LCA can be useful if the environmental performance is debated or depend on very complex man-made flows. A simplified LCA can suit a case where the organisational processes are expected to be complicated or to determine the environmental performance to a high degree. The use of existing LCA results is only feasible for products where such studies that still are valid and that have scopes that are similar to the scope of the socio-material flow study. LCA is preferably performed using the standardised procedure and guidelines provided by, for example, Hauschild et al (2018). This procedure, among other, includes goal and scope definition, inventory of man-made flows, assessment of the potential environmental impacts of these flows, and interpretation of the assessment results. LCA can be used in a socio-material flow study for either of the two major purposes of comparing the environmental performance of two different but substitutable product life cycles, and of identifying the environmentally most impacting technical processes in a product life cycle.

Step 2 can be based on information gathered during Step 1 and on qualitative studies of documents, interviews, and observation (e g, Silverman 2006). Because SMIPs occur at the man-made flow and are connected to each other via action nets, we have found it useful, as a starting point, to interview persons that have both an overview of a range of activities in, for example, a company and who has experience of or knowledge about how different persons perform at the SMIPs.

We have found it useful to perform Step 3 by carrying out qualitative organisational studies that can be based on documents, interviews, and observation (e g, Silverman 2006). Because one person or other source of information typically only is familiar with some parts of an action net and has personal opinions, we have found it useful to interview actors that are expected to disagree on one or more environmentally relevant aspects.

Steps 4 and 5 connect the information and findings from Steps 1–3.

Both material flow studies and studies of action nets can be performed with the aid of discourse analysis and conversation analysis (Silverman 2006) as interpretation filters. These two methods enable a critical selection of information from quantitative measurements of man-made flows and explanations of human actions. Discourse analysis points out that all communication, including talking, is used to perform interactions. This applies to any person, including researchers. Conversation analysis is similar by scrutinising communication processes, but focuses specifically on talk and the details regarding when the involved persons speak during a conversation and about what. The approach is useful for realising that interviews likely result in more representative replies if the conversation smoothly continues from the latest previous statement.

6.4 Tested scopes

Different variants of the socio-material flow methodology have been tested. The variants have differed from each other regarding two primary aspects. The first aspect concerns the balance between material flow studies and action nets studies has varied between the variants. The flow has been the primary study object when the environmental impacts were expected to vary largely between compared alternatives. The second aspects concerns how many actors that are studied along a man-made flow. If several environmentally important flows meet in the activities at one company, it can make sense to focus the action net study on this organisation. Based on the two types of difference, three methodology variants, outlined in the following, have been developed. The variants are the life cycle nodal organisation (LCNO) study, the actor LCA approach, and the product chain organisation (PCO) study. They are outlined in the following and presented in Figure 7.

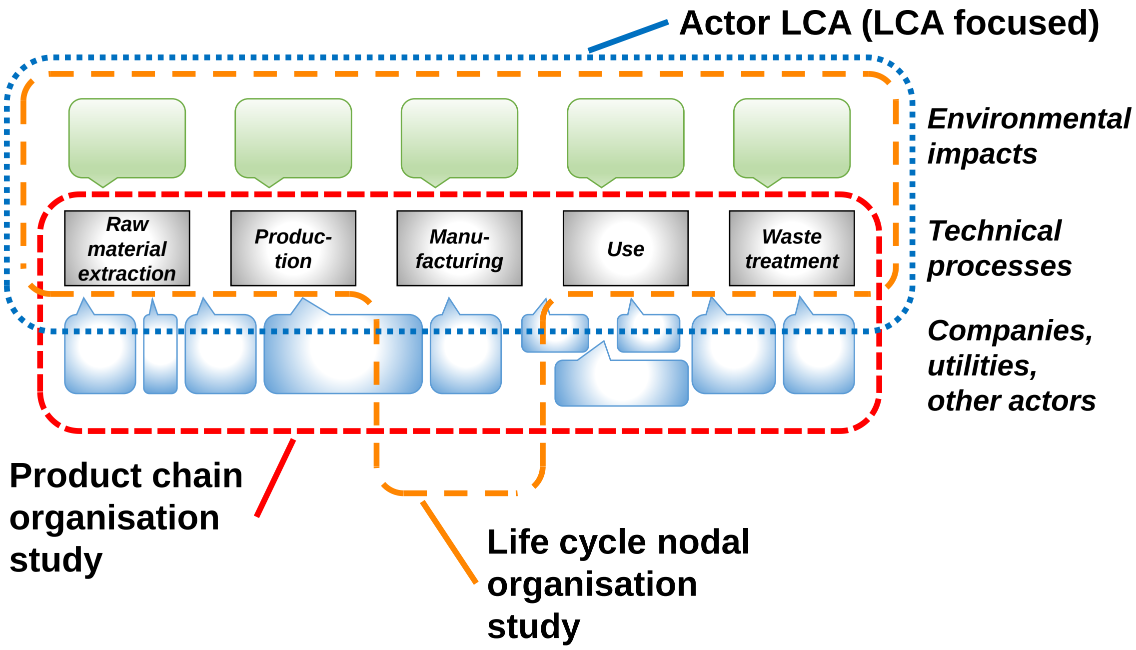

Figure 7: Main variants of the socio-material flow methodology. LCA = life cycle assessment. Adapted from Baumann et al (2015).

A *life cycle nodal organisation* (LCNO) study is concerned with the environmental impacts from a whole product life cycle and the action net around a node in one technical life cycle process where environmentally important man-made flows meet. As an example of a finding from an LCNO study, the case on bread in Paper III can be used. One of the findings from the study was that the bread discarding at one bakery's retailers had become alarmingly high due to a lack of coordination of production and sales, and varying customer demand. The studies can be carried out both *in-depth LCNO* studies and using the *screening LCNO* approach introduced in Paper III. The large amount of time and effort needed for an in-depth LCNO study (Brunklaus 2009) warrants the screening perspective.

Actor life cycle assessment (actor LCA) can be used when the environmental impacts and product life cycles are particularly environmentally relevant to study in detail. The approach combines LCA with studies of the choices actors along the man-made flow can make and of the types of communication between these actors. Actor LCA can be illustrated with a case study that compared low-energy buildings and conventional buildings (Brunklaus et al 2010). The results showed that the choice of green electricity or not by residents had a large effect on the environmental performance of the product life cycle. The building constructors, however, were found not to be aware of the importance of this choice.

In a *product chain organisation* (PCO) study, a combination of the action net along a large part of a product life cycle and its environmental performance is studied. The PCO approach puts less emphasis on detailed studies of environmental impacts than the LCNO and actor LCA variants. PCO studies are designed for cases where environmental impacts are influenced to a high degree by the interaction between actors along the man-made flow. To exemplify this interaction, one of the finding on metal packaging in Paper IV can be used. A policy on metal packaging recycling in Sweden turned out to be based only on reports from packaging producers on produced amounts. The reporting turned out to be incomplete because a large share of the production was performed by actors that did not report. All the recycled material was, however, reported. Therefore, the calculation of the recycling rate as the difference between production and recycling resulted in a too high reported recycling rate. PCO studies can be performed both as *single PCO* studies for single products and as *broad PCO* studies for large groups of products. Single products have been covered in a study on chocolate used for a specific type of ice cream (Afrane et al 2013). Broad PCO studies have been carried out on among other batteries in electrical vehicles (Baumann 2012).

The different scopes have been developed for identifying key actors and key connections effectively and therefore vary regarding the extent to which and where man-made flows and action nets are studied.

6.5 Overview of the methodology

An overview of the methodology and how this chapter presents it, is shown in Table 3

Table 3: Overview of the contents of the socio-material flow methodology and of where it is presented.

Aim	Concepts	Procedure	Tested scopes
Sub-Chapter 6.1	Sub-Chapter 6.2	Sub-Chapter 6.3	Sub-Chapter 6.4
Through application assisting actors such as managers, policymakers, and non-governmental organisations (NGOs) in performing environmentally effective actions	Types of study: - Material flow study - Study of action nets Core concepts: - Man-made flow - Socio-material interaction point (SMIP) - Action net Additional concepts: - Limited connection - Incompatibility between alternatives	A sequence when using the methodology Data collection techniques Analytical methods	Three primary variants: - Life cycle nodal organisation (LCNO) study - Actor life cycle assessment (actor LCA) - Product chain organisation (PCO) study

7 Contributions from similar research, field studies, and concepts (Papers I–V)

This chapter relates the five papers in the dissertation to the whole dissertation. Sub-Chapters 7.1–7.5 present one paper each and Sub-Chapter 7.6 summarises findings that support the thesis.

7.1 Early research on actors and man-made flows (Paper I)

Paper I presents an overview of four previous case studies that in different ways extend life cycle assessment (LCA) to the actors that determine the environmental performance of the man-made flows.

Method

The paper summarises and synthesises findings from four case studies. The paper is based on case study publications from 2001 (Ekdahl 2001) and 2009 (Löfgren 2009) and analysis from 2004 (Baumann and Tillman 2004) on manufacturing life cycle actors, a 2008 paper on dairy life cycles (Berlin et al 2008), and a 2010 paper on life cycles of conventional residential buildings and of *passive houses* (Brunklaus et al 2010).

Contribution from the paper to developing the socio-material flow methodology

Based on the paper, LCA ought to be complemented by four considerations (adapted from Paper I, p 82):

- Identification of the extent to which a decision maker along a product life cycle can influence other product life cycle actors (Baumann and Tillman 2004, based on Ekdahl 2001)
- Consideration of how a specific decision maker along a product life cycle influences environmental impacts in whole product life cycles (Löfgren 2009)
- Division of life cycle assessment (LCA) results by product life cycle actors rather than life cycle phases or technical processes, and assessment of best improvement action for each actor (Berlin et al 2008)
- Evaluation of who is the most influential actor, and evaluation of the impact from the actors' ability to put demand on other actors along the product life cycle (Brunklaus et al 2010)

7.2 Reviewing matters of concern in industrial ecology (Paper II)

Paper II contributes with a critical review (Paré et al 2015) on complexities in how man-made flows are handled by action nets. The paper discusses how nine industrial ecology-related articles (primarily from journals) cover different aspects of the actor-network-theory (ANT) concept of *matters of concern* (Latour 2004). Matters of concern are matters that are not settled and that social construction still shapes. The matters of concern concept contrasts taken-for-granted *matters of fact*. For industrial ecology, matters of concern would relate to controversial issues on the sustainability relevance of how humans influence man-made flows. Paper II contributes to developing and testing the socio-material flow methodology by revealing not in Paper I covered types of how actors are important for man-made flows and change towards sustainability.

Method

The primary approach in the study was a critical review (Paré et al 2015) of selected publications related to industrial ecology. A critical review is a type of review where the reviewer studies the literature in relation to a point of reference. Critical reviews differ from the broad analyses performed in systematic reviews. The point of reference in this particular review was the ANT focus on disputed matters of concern as opposed to taken-for-granted matters of fact (Latour 2004).

Summary of findings in the paper

The paper presents an overview and analysis of nine articles on matters of concern for man-made flows. The articles relate to product life cycles or to industrial ecology more generally. Table 4 lists the articles.

Table 4: Overview of the articles in the review on matters of concern for industrial ecology. Adapted from Paper II, page 8.

Authors	Publi-cation year	Title	Journal (J) or conference (C)
Product chain studies			
Baumann & Camacho Otero	2016	One, two, three, many! or…? Mapping of the controversy over the Swedish West Coast shrimp	C: 22nd International Sustainable Development Research Society Conference
Freidberg	2018	From behind the curtain: Talking about values in LCA	J: The International Journal of Life Cycle Assessment
Lazarevic	2018	The legitimacy of life cycle assessment in the waste management sector	J: The International Journal of Life Cycle Assessment
Other industrial ecology studies			
Fischer-Kowalski & Steinberger	2011	Social metabolism and hybrid structures	J: Journal of Industrial Ecology
Newell & Cousins	2014	The boundaries of urban metabolism: Towards a political–industrial ecology	J: Progress in Human Geography
Wallsten & Krook	2016	Urks and the urban subsurface as geosocial formation	J: Science, Technology, & Human Values
Other industrial ecology-related studies			
Spangenberg	2011	Sustainability science: A review, an analysis and some empirical lessons	J: Environmental Conservation
Dijk et al.	2017	Sustainability assessment as problem structuring: Three typical ways	J: Sustainability Science
Shove	2018	What is wrong with energy efficiency?	J: Building Research & Information

The review of the nine publications revealed a range of disagreements on claims of high relevance for sustainability and industrial ecology. Many practitioners of industrial ecology practitioners may be aware of these claims but do not communicate this awareness. The paper reveals three themes in the reviewed literature: whether ‘scientificness’ is useful or not (e g, Lazarevic 2018), complexities in and in the relations between controversial aspects of how flow systems are handled by humans (e g, Wallsten and Krook 2016), and disagreements on the meaning of sustainability as a concept (e g, Baumann and Camacho Otero 2016). The review showed that scientific rigor in the design of a method in industrial ecology can either lead to increased or decreased trust by a non-academic actor in the method (e g, Lazarevic 2018). Complexities related to controversies were in the literature found on lack of connections between different disagreements (Wallsten and Krook 2016), how one sustainability controversy linked to other controversies (Baumann and Camacho Otero 2016), and that researcher ought to consider overarching sustainability issues such as the size of the economy (Fischer-Kowalski and Steinberger 2011). The disagreements on the concept of sustainability cover whether the term is about securing employment or sustaining nature (Baumann and Camacho Otero 2016) and decision-makers interpreting increased energy efficiency as a sustainability approach despite that energy demand increased more rapidly than the efficiency (Shove 2018). These sustainability issues in industrial ecology of scientificness, complexity of controversies, and the meaning of sustainability pose large challenges for studies of and decisions on man-made flows and, therefore, for sustainability.

7.3 Screening of environmentally relevant socio-material interactions (Paper III)

The development and test of a screening approach for the study of how product life cycle environmental impacts depend on organisational processes where environmentally important flows meet could both validate an efficient socio-material flow methodology and show its applicability to a range of types of products. The study covered the five primary test cases (with three sub-cases within each of the five primary cases):

- Bowling
- Bread
- Coach services
- Concrete
- Road management

The paper’s contribution is a screening method that helped validate the socio-material flow methodology and to show its applicability to a wider range of products and services than had previously been studied (i.e. residential and commercial property management).

Method of the test of the screening

A proposed screening life cycle nodal organisation (LCNO) approach (I describe it in Chapter 6 in the dissertation) was tested in the five cases of bowling, bread, coach services, concrete, and road management. In the testing of the screening LCNO methodology, the five different cases were used in order to evaluate the applicability of the methodology in a range of settings. The cases represent a broad spectrum of products and services and can, therefore, show whether the screening LCNO methodology is general applicable. Each product case covered a comparison between three specific companies or other units. Each comparison involved specific bowling halls, bakeries, coach routes, cement plants and road management areas, in the southwest of Sweden. When selecting the sub-cases, the focus lay on enabling the identification of organisational differences and, therefore, the sub-cases within each primary case were chosen to have minimal geographical and other differences between them, in order to increase the opportunities for identifying organisational practices in one action net that could be adapted to another action net.

Desk studies as well as field studies were used in each of the five primary cases. The observation and interviews were chosen in order both to be close to the SMIPs and to get overviews of the action nets.

Summary of findings in the paper

The five test cases resulted in the identification of 25 situations where the organisational processes at the nodes influence product life cycle environmental performance via socio-material interaction points (SMIPs). The types of situations are outlined in Table 5.

Table 5: Situations that influence the product life cycle environmental performance of the five primary test cases. Adapted from Paper III, page 467.

Groups of situations	Specific situations and their relations to environmental performance
Bowling – bowling halls	
Types of services	Disco bowling – lane wear and bowling time
	Additional games – equipment impacts and bowling time
	Restaurants, bars, and kiosks – impacts from these services and bowling time
	Lunch provision – fill rate of the premises
Maintenance	Level – equipment impacts and repair needs
Ceasing of business	Utilisation rate, and types of services and maintenance
Bread – bakeries	
Supply	Distance increase
	Optimisation
Production	Product types – loaf thickness
	Sealed production – durability and consumer storage
	Packaging – packaging production and waste management impacts, durability, and consumer storage
Distribution	Distance
Retail	Discarding
Coach services – coach routes	
Vehicle sourcing	Fleet age
	Seats per row
Garage related	Location
Passenger transport	Eco-driving: drivers performing and comparing experiences of it
	Smooth driving
	Scheduling related to rush hours
Concrete – cement plants	
Emission reduction techniques	Production permit renewal processes
	Production permit renewal frequency
Maintenance	Malfunctioning routines
Road management – districts for operation and routine maintenance of roads	
Transports between districts	Centralisation by contractors – increasing transports
Operation and maintenance	Change of contractor – withholding of expertise
	Fragmentation of procuring agency – difficult to handle the overarching environmental issues

Three examples can be used to illustrate the identified environmentally relevant situations. The first relates to bowling. Only one of the studied bowling halls provided the combination of lunch and bowling. This could lead to lowered environmental impacts per bowling occasion because of better fill rates of the premises and consequently lower impacts per occasion from building related services that can be caused by a leisure service (cf., Tengström and Izurieta 2010). The second example deals with bakeries and bread. Along the bread product life cycles, discarding activities differed between the studied sub-cases. The aim at one bakery was that 3% of the bread was not sold in order for customers to be able choose from a wide range of products. At the retailers of another bakery, the discarding levels had become high because the customer demand varied to a higher degree and the coordination between the bakery and the retailers had decreased. Discarding leads to a need for additional bread production, which in turn results in an increase in environmental impacts from the product life cycles (Andersson and Ohlsson 1999). The third example considers concrete and cement production. The importance of repeated action was illustrated for one of the cement plants by court proceedings (Växjö Tingsrätt 2007) and an environmental report (Cementa 2008). After a long negotiation process for a new plant production permit, the nitrogen oxides emissions had been considerably lowered. They reached a level 40% below the level plant representatives initially had claimed to be the lowest possible.

7.4 Analysing environmentally relevant governance that relates to recycling (Paper IV)

A two-country comparative product chain organisation (PCO) study was conducted to test the applicability and usefulness of the socio-material flow methodology for a policy context. The comparison looked into the governance of product life cycles of metal packaging under extended producer responsibility in Sweden and the Netherlands and is described in Paper IV.

Method

The broad PCO approach (I describe it Chapter 6 of the dissertation) was tested as a means to provide guidance to material efficiency governance through an application to metal packaging flows.

Regarding the testing of the broad PCO approach on governance of metal packaging flows, the cases of Sweden and the Netherlands were compared and a subsequent discussion in relation to LCA and other approaches was performed. The two countries were selected because, among other, the reported metal packaging recycling rates were typically around 10 to 20 percentage points higher for the Netherlands than for Sweden (Eurostat 2017). In addition, a comparison between the countries could produce practical suggestions for action because both of the countries have followed the same European Union (EU) Directive on packaging waste and because of the large similarities between the metal packaging in the two countries.

The study covered steel and aluminium packaging, the product life cycles of the metal packaging discarded in the two countries, and a time frame from the early 1990s to 2017. Data was collected from 46 text sources, 5 interviews with industry and public agency representatives, and 4 combined visits and interviews at collection stations and one intermediate storage facility.

Summary of findings in the paper

To begin, metal packaging flows were described for each country and analysed from an environmental perspective. Next, SMIPs and action nets were added to the description. Figures 8 and 9 show the organisational processes connected to the product flows of metal packaging in the two countries.

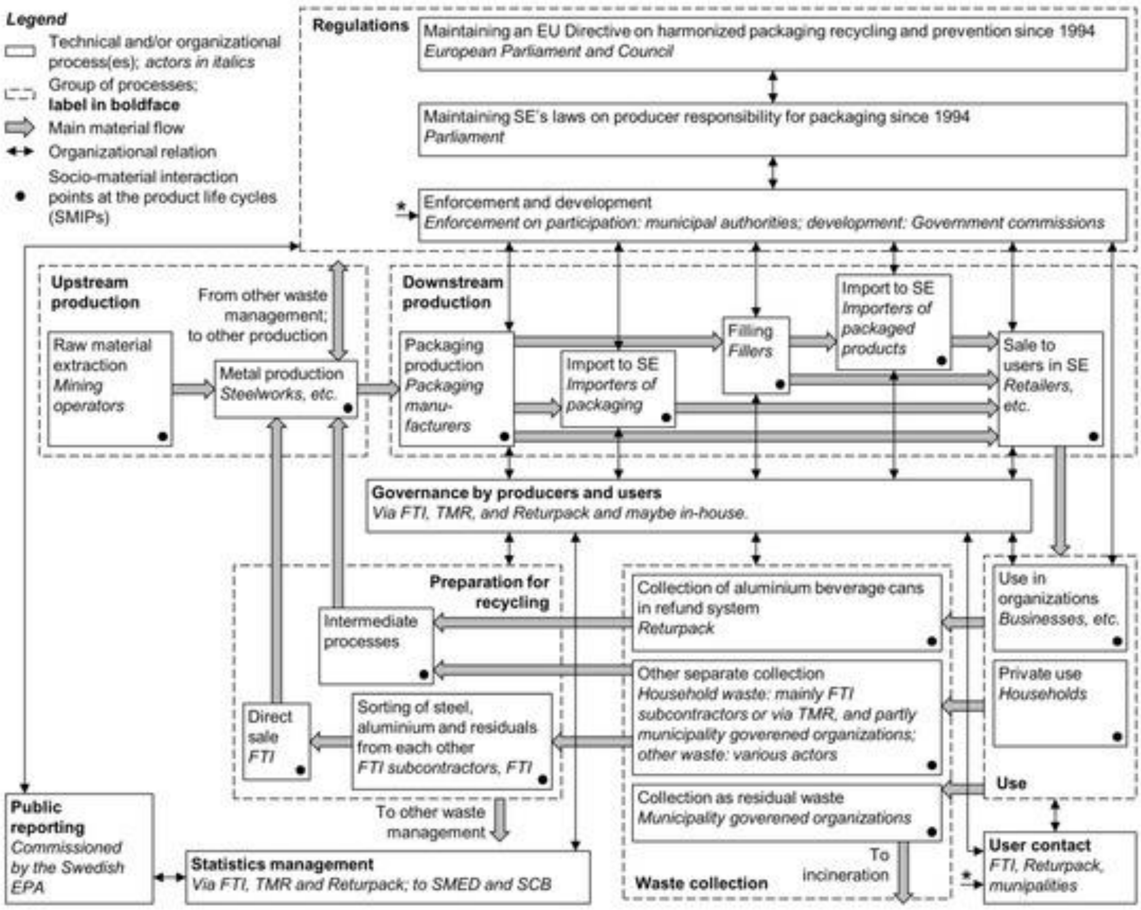

Figure 8: Central flows and organisation identified in the Swedish metal packaging product chain organisation, primarily for 2013–2017. The flows in “Downstream production” include import to Sweden of both filled and at the import not yet filled packaging. The two * signs represent an organisational relation (otherwise shown by a double arrow line) between “Enforcement and development” and “User contact”. Abbreviations: EU = European Union, FTI = Förpacknings- och Tidningsinsamlingen, SCB = Statistics Sweden, SE = Sweden, SMED = Svenska MiljöEmissionsData, Swedish EPA = Swedish Environmental Protection Agency. Adapted from: Paper IV, page 8.

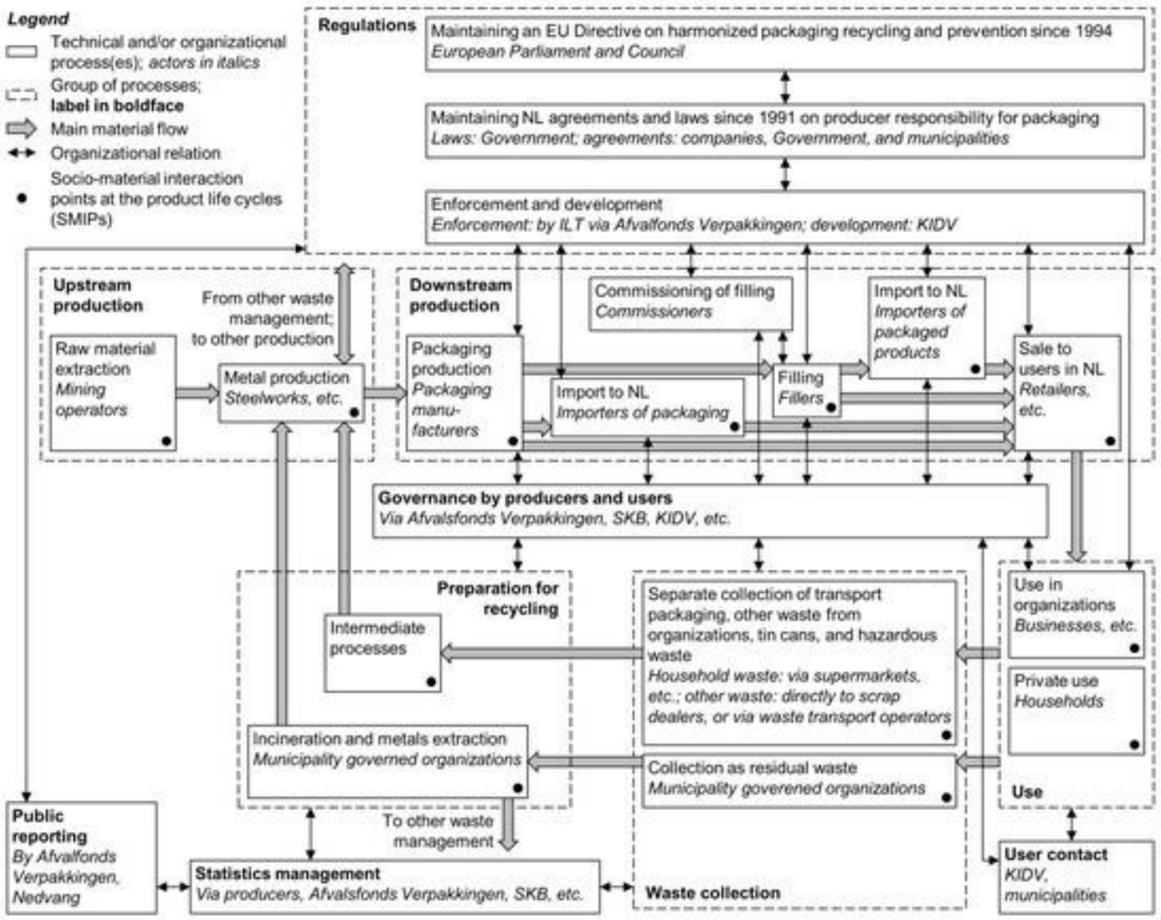

Figure 9. Central flows and organisation identified in the Dutch metal packaging product chain organisation, primarily for 2013–2017. The flows in "Downstream production" include import to Sweden of both filled and at the import not yet filled packaging. Abbreviations: ILT = Inspectie Leefomgeving en Transport, KIDV = Netherlands Institute for Sustainable Packaging, NL = the Netherlands, SKB = Stichting Kringloop Blik. Adapted from: Paper IV, page 11.

An analysis was performed of how specific actions influence the environmental performance of the metal packaging flows in the two countries.

The environmental assessment showed sizeable impact, especially related to bauxite mining and aluminium volumes used for packaging. An increase in rates decreases these impacts substantially. Because of this, the conditions around recycling, recycling rates, and consumption amounts for both steel and aluminium packaging were looked into. The Swedish recycling uses separation at the source of waste generation. In the Netherlands, the recycling material comes from both such source separation of waste and separation after incineration of municipal solid waste. Because such incineration only oxidises a very small fraction of the metal packaging (Görling 2013, personal communication), the incineration plants produce metal packaging waste that suits recycling processes that use considerably less energy than production from ore (cf, Stichting Kringloop Blik 2007).

The action nets were found to influence the environmental performance via inaccurate statistics, mixing of waste streams, and consumption. The starting points for these environmentally relevant actions are presented in Table 6. In order to exemplify the analysis, further details are here provided about the statistics being based on the recycling but not the production of packaging from *free riders* and extraction of other valuable metals influencing extraction from incineration ashes. The free riders was an issue for the follow-up in Sweden. In the official Swedish metal packaging governance, the recycling rate was a key indicator. The rates were calculated as recycling of discarded packaging per production. This was problematic because of inclusion of recycling but not production from actors not officially registered as metal packaging producers (referred to as free riders). In 2005, an estimated 9.6% of the Swedish metal packaging was produced by free riders (Naturvårdsverket 2012). The registration was mandatory but difficult to enforce. Extraction of the metals in metal packaging waste from municipal waste incineration ashes was used in the Netherlands but not in Sweden. Because the municipal waste also contained very valuable metals, the extraction techniques had become highly refined. Consequently, the recovery rates of steel and aluminium from packaging had considerably increased in the Netherlands. Because a different method for treating the waste stream was used in Sweden, a similar increase of recycling rates had not occurred in Sweden.

Table 6: Starting points for understanding how actions have influenced the environmental performance of metal packaging flows in Sweden (SE) and the Netherlands (NL). Adapted from Paper IV, page 15.

Theme	Actions
Inaccurate statistics	SE: The statistics have been based on the recycling but not the production of packaging from *free riders*, thereby leading to errors when calculating the recycling rate as recycling per production.
	NL: The statistics have been based on estimates of extraction from ashes that are difficult to get accurate.
	SE: There has been limited evaluation of the accuracy of the statistics.
Mixing of waste streams physically and in policies	Both countries: Aluminium and steel flows have been treated as one flow in the policies.
	NL: Non-functional incineration of metal packaging waste in residual waste.
	NL: Extraction of other valuable metals has driven extraction from incineration ashes.
	SE: Investigations on mixing streams led to keeping the separation between the materially incompatible streams of metal packaging and other household metal waste.
	SE: Misunderstandings has contributed to not complementing source separation with extraction from ashes.
Consumption	Both countries: Use of qualitative goals but not incentives for absolute reduction of packaging material.

7.5 Conceptualising a socio-material approach to man-made flows (Paper V)

In Paper V, experiences from the many case studies and learnings from theoretical studies are synthesised into a held-together methodology for socio-material studies of man-made flows. The contents of the paper are presented throughout this dissertation.

7.6 Summary of methodology relevant findings from the five papers

As a starting point for analysing the relevance of the methodology for environmental decision-making, I here present a summary of methodology relevant findings from the five papers in the dissertation.

Paper I shows examples of how some actors more than other actors can influence the environmental performance of a man-made flow. The examples highlights the relevance to base decisions on a combined understanding of actors and man-made flows. Paper I, however, does not present a systematic approach to choose and study actors' influence on the flows, which suggests that application of a systematic socio-material flow methodology can provide further guidance for environmental decision-making.

Paper II shows the presence of critical complexities in action nets handling man-made flows. The development of the socio-material flow methodology has shown that such complexities exist and cannot be extracted from LCA and material flow analysis (MFA) maps and quantifications of man-made flows. Therefore, the importance of the complexities presented by Paper II supports the use of a systematic socio-material flow methodology that can reveal such complexities. Furthermore, the reviewed publications that Paper II covers do not themselves provide such a methodology.

Table 7 summarises the findings in question from Papers I and II.

Table 7: Findings that support a discussion on why the socio-material flow methodology can guide decision-making towards sustainability.

Aspect that relates to usefulness for environmental decisions	Summarised findings based on the papers	
	Overview of earlier studies on actors and life cycle assessment (LCA) (Paper I)	Review of critical complexities on how actors handle man-made flows (Paper II)
Existing understanding of that actors matters for environmental sustainability	- Variation shown between how much different actors and actions influence the environmental performance of a product life cycle	- The handling of man-made flows can be conditioned by the level of 'scientificness', by complexity of and between controversies, and disagreements on the meaning of sustainability
Lack of a more systematic approach	- Only a few and loosely connected studies in Paper I	- No systematic approach is presented on how to study critical complexities in how humans handle man-made flows

The two case studies (Papers III and IV) cover findings that clarify the practical feasibility of using the socio-material flow methodology. One aspect is the identification of environmentally relevant organisational processes. The identification of these processes by using the methodology shows both the presence of the processes and that the methodology can be a tool for finding them. Another aspect is the ability to vary the methodology regarding which parts of a man-made flow and action nets to study and to which extent. At a more detailed level, the versatility of the methodology depends on how well it can be applied to different types of man-made flows and even specific flows related to, for example, a product. Table 8 summarises the findings that relate to these aspects.

Table 8: Findings on practical feasibility of the socio-material flow methodology.

Aspect of practical feasibility	Summarised findings based on the papers	
	Cases for testing a screening approach (Paper III)	Cases for testing the methodology on waste management (Paper IV)
How organisational processes, besides technology, influence man-made flows	- 25 situations identified, based on Table 5	- 9 situations identified, based on Table 6
Different foci between man-made flows and organisation	- A quicker variant of life cycle nodal organisation (LCNO) studies was successfully tested	- The variant broad product chain organisation (broad PCO) studies was successfully applied
Different foci along man-made flows	- Successful application with a focus on production and consumption	- Successfully tested with a focus on waste management
Applicability to different products and sectors	- Successful application to product life cycles of bowling, bread, coach services, and road management	- Successful application to product life cycles of metal packaging

Finally, the conceptual study (Paper V) includes findings that relate to the conceptual clarity of the socio-material flow methodology. The development of a held-together socio-material methodology represents a contribution because it provides an updated and generalised socio-material methodology. The generalisation includes a synthesis of the different variants of the methodology, and a focus on the methodology, its concepts, and its other elements rather than primarily on case study findings. The use of three systematically posthumanist approaches as a more specific basis for the methodology provides a link between ontologies and the design of the methodology. Table 9 summarises the findings concerning the conceptual clarity of the socio-material methodology.

Table 9: Findings on conceptual clarity of the socio-material flow methodology.

Aspect of conceptual clarity	Summarised findings based on the conceptual study (Paper V)
Developing a held-together version of the methodology	Presentation of an updated methodology A methodology focused description of and reasoning about: - two types of study - five additional concepts - a procedure - an explorative and critical approach - tested scopes
Specifically relating the methodology to three systematic and posthumanist approaches	The approaches actor-network-theory (ANT), object-oriented ontology (OOO), and agential realism are presented regarding: - being systematic in the sense of prioritising material and human aspects equally - being part of an array of studies in the social sciences and humanities that are posthumanist and align with combining material flow studies and studies of human actions - the fundamentals of the three approaches - two concepts in the methodology being derived from the three approaches

8 A discussion about the relevance of a socio-material flow methodology for decisions towards sustainability

In this chapter, I, based on the findings in Papers I–V, discuss the implications of the socio-material flow methodology for decisions towards sustainability.

8.1 Methodological advantage compared to life cycle assessment

The problem of using conventional flow methodologies, such as life cycle assessment (LCA), to inform decision-making is that such a study typically does not provide any description of which and how actors can and cannot influence a certain technical process and thereby environmental performance (cf, e g, Baumann and Tillman 2004). A practitioner performing an LCA study may have knowledge about actors' actual roles and opportunities, but the technically and environmentally focused material flow studies do not require or guide documentation and further communication of the roles of action nets for the flows. Paper I–II show the considering the roles of actors for the flows matter (see Table 7). In addition, action nets can contain conflicts and complex relationships between actors and of relevance for environmental sustainability, as shown by Paper II (see Table 7). Using material flow studies could be limiting if an omission of human actions obscures conditions for change and improvement towards sustainability.

Decision-making can receive more environmentally effective guidance than from a material flow study from an approach that both considers the man-made flow and how networks of humans handle and determine the flow. A comparison of the socio-material flow methodology and an organisational LCA (O-LCA) can illustrate the contribution of the socio-material methodology (Lindkvist and Baumann 2019). O-LCA expands the LCA focus by considering whole product portfolios, in order to be more relevant for decision-making. An O-LCA study, however, does, like LCA, only very little consider the action nets determining the flows. Figure 10 illustrates the difference between the guidance for environmental decision-making that O-LCA and the socio-material methodology can provide.

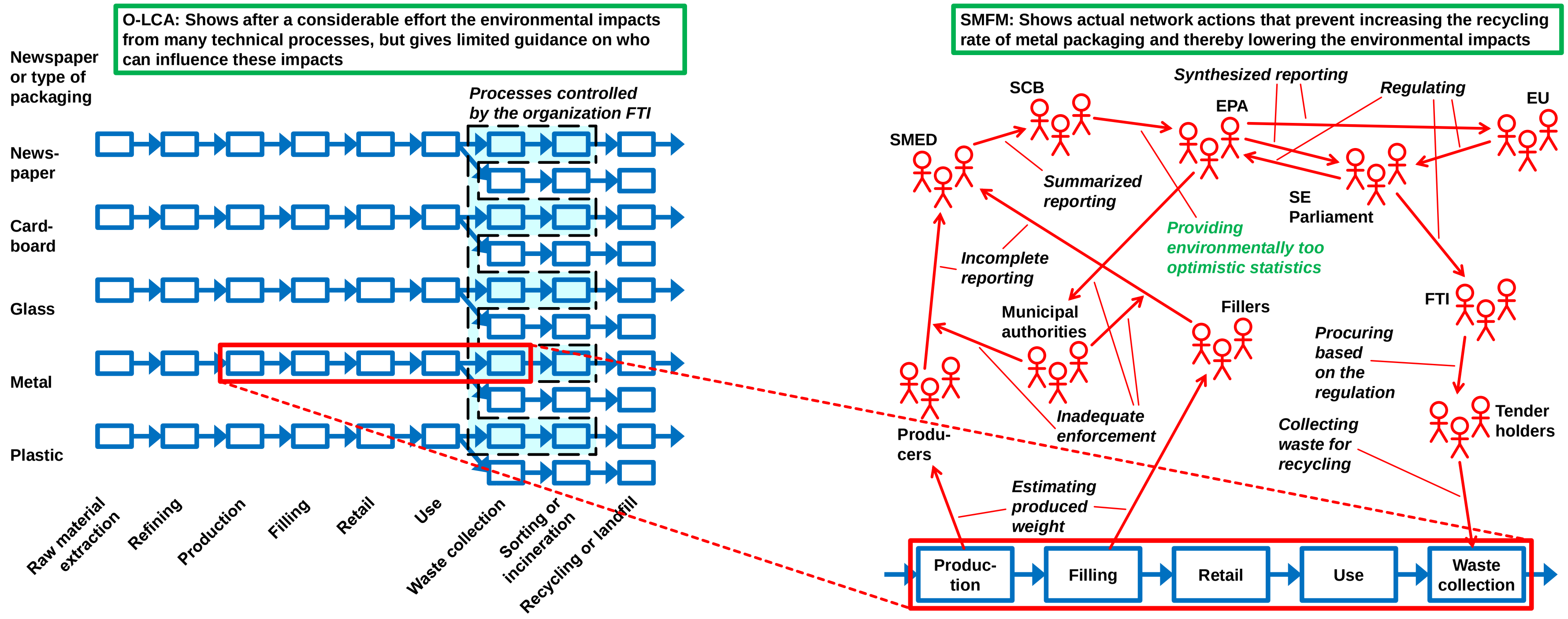
O-LCA: Shows after a considerable effort the environmental impacts from many technical processes, but gives limited guidance on who can influence these impacts
Newspaper or type of packaging
News-paper
Card-board
Glass
Metal
Plastic
Processes controlled by the organization FTI
Raw material extraction
Refining
Production
Filling
Retail
Use
Waste collection
Sorting or incineration
Recycling or landfill
SMFM: Shows actual network actions that prevent increasing the recycling rate of metal packaging and thereby lowering the environmental impacts
SMED
SCB
EPA
EU
SE Parliament
FTI
Fillers
Municipal authorities
Produ-cers
Tender holders
Synthesized reporting
Regulating
Summarized reporting
Providing environmentally too optimistic statistics
Incomplete reporting
Inadequate enforcement
Procuring based on the regulation
Collecting waste for recycling
Estimating produced weight
Produc-tion
Filling
Retail
Use
Waste collection

Figure 10 (previous page): Explanation of typical findings from organisational life cycle assessment (O-LCA) (left) and when the socio-material flow methodology (SMFM) is included (right), on the Swedish organisation FTI and packaging recycling. Source: Lindkvist and Baumann (2019).

8.2 On the practical feasibility of using the methodology

A methodology is only relevant if users can apply it and commissioners find the results from this application to be relevant. This practical feasibility depends on if application of the methodology can generate results that are of value for decision makers, can be carried out in different situations, and can be performed within reasonable time frames with existing competencies, and if data is available.

Interesting and valuable results

Case studies for developing and testing the methodology have produced a range of different results on how environmental performance depend on action nets (e g, Paper IV), as illustrated in the following. The results go well beyond the outcome of, for example, LCA.

The findings from Papers III and IV relate to supply, waste management, staying in business, statistics, and misunderstandings, among other. One of the findings on bread discarding can be used as an example from Paper III. The discarding at retailers for one of the studied bakeries had become high due to among other varying customer demands and a decrease in the coordination between the bakery and the retailers. The discarding depended on organisational processes rather than differences in technical aspects related production machinery and distribution vehicles, and the resulting income losses were too low to motivate action. The varying demand is a process that a bakery cannot direct but the staff could, in order to decrease the discarding, consider organisational changes such as monitoring the demand more closely and lowering the price of bread that might otherwise not be sold. In Paper IV, the finding on *free riders* making statistics on metal packaging recycling unreliable in Sweden can be used as an example. The free riders were a statistics problem because the governance was based on official statistics that included packaging from the free riders in the collected amounts but not in the produced amount and because it was practically difficult to find free riders and make them join the national registry and report.

Other studies applying versions of the methodology have shown that a style in residential properties management that was adjusted to actual building characteristics resulted in far less environmental impacts than emergency-oriented management (Brunklaus 2009), differences among a product life cycle’s actors regarding environmental priorities (Afrane et al 2013), and customers lacking visibility of environmental impacts (Gullbring et al 2010).

Discussions with industry representatives and industrial ecology researchers have revealed that they find LCA to give too little insight into the complex action nets that determine the environmental performance of man-made flow (e g, Le Blévennec 2019, personal communication). Whether this concern is common in industry and whether the application of the socio-material flow methodology can produce results that respond to the concern can be subjects for further research.

Applicability to different situations

The feasibility of the methodology depends on whether a user can apply it to a range of different situations, such as different products. Case studies for developing the methodology have applied it with different organisational scope, with foci on different parts of product life cycles, and for different products and services, as exemplified in the following.

Depending on whether better understanding for decision-making is needed primarily about a man-made flow or the organizing of it, the socio-material methodology can be applied using the different organisational scopes presented in Sub-Chapter 6.5. Case studies have successfully tested to explain environmentally important organisational connections along whole product life cycles in product chain organisation (PCO) studies (e g, Paper IV). Life cycle nodal organisation (LCNO) studies revealed complexities of sustainability relevant organising of product life cycle nodes where environmentally important flows meet (e g, Paper III). Finally, actor life cycle assessment (actor LCA) applications have connected beforehand only to a limited degree understood environmental performance of a product life cycle to relations between actors along it (Brunklaus et al 2010).

If one part of a man-made flow is known to be a promising candidate for changing the organising of, a socio-material flow study can focus on these organisational processes and flows. Case studies have been successfully applied with different foci along man-made flows – on difficulties of environmentally sound management of production (e g, Paper III), environmentally important but only to a small degree earlier realised influence of consumption (e g, Brunklaus et al 2010), and complexities of governing waste streams (Paper IV).

Finally, the characteristics of man-made flows and organisational processes can vary substantially among, for example, different products and services. Application of the socio-material methodology has shown how commercial building management depends on complex organising (Lundberg 2008), that metal packaging recycling depends on non-intuitive organising around statistics and misunderstanding between actors (Paper IV), and differences between the meaning of sustainability for different actors along a product life cycle of ice cream (Afrane et al 2013).

The testing of the socio-material methodology on different organisational scopes, different parts of man-made flows, and different products and services has revealed a variety of environmentally relevant organising. These results show both the flexibility of the methodology and the usefulness of studying how organising influences man-made flows in a range of different situations rather than assuming that a certain type of organising is environmentally preferable.

The different applications show that a user can apply the methodology in order to explain how the organising determines the environmental performance of man-made flows. The feasibility, however, also depends on the competency needed, and the next Sub-Sub-Chapter reasons about this.

Preparing a study of the organising of man-made flows: interest, competency, and man hours

How can the socio-material be of practical relevance for change towards sustainability? A first step can be to identify the actors that use of the methodology could guide.

Decision-makers such as managers, policy-makers, and representatives for non-governmental organisations (NGOs) are key environmental actors because of the possibility for them to gather information required for broader overviews of different activities and the power of these actors to realise change. The broader overview is useful, because material flow methodologies such as LCA have shown the non-intuitive effects of actions on environmental performance because this performance depends on complex man-made flows.

In addition, a man-made flows are already considered by decision-makers (cf, Stewart et al 2018). A study of around 50,000 corporate sustainability reports found that around 5% of them between 2005 and 2015 in Europe and around 2% to 3% of them in Japan between 2013 and 2015 referred to LCA (Stewart et al 2018). For managers, the actual influence on environmental impacts from a man-made flow is necessary to consider, for example, if they report materials use according to a 2018 Global Reporting Initiative Standard (GRI 2018).

A basis and an interest in flows, therefore, exists in and in relation to companies. In relation to other actors, decision-makers could both influence these, and receive pressure from them regarding following certain principles (and by consequence, methodologies) for environmental decisions.

Research-driven case studies have shown that the competency for applying the socio-material methodology exists. Students with relatively limited amount of training in using the methodology have applied it in case studies of, for example, organising product life cycles of ice cream (Afrane et al 2013) and the filling material of nappies (Gullbring et al 2010). The case studies have not required too many working hours in relation to the environmental decision-making relevance of the findings from the studies. The studies have included fieldwork, such as interviewing and observation. Engineers are often not familiar with this type of study, but social scientists could contribute by performing these parts of the studies. Finally, it remains to test whether the methodology also is feasible to apply in a practical situation where decision makers aspire to perform change towards sustainability rather than where researchers aim to develop the conceptualisation in the methodology.

Data availability

The actual practical feasibility of using the methodology also depends on how readily available and representative collected data are and how well the intended recipients could utilise the findings. In the studies reported on in Papers III and IV, the explorative and socio-material approach was found to be useful; during interviews and observation, the information encountered was not found to be predictable and often involved many different types of aspects at the same time. In addition, the ability for interviewees to talk largely freely coincided with that they provided a large amount of environmentally relevant information in a short period.

8.3 On the conceptual contribution of the presented methodology

I have assessed the conceptual contribution of the socio-material flow methodology by reasoning about its concepts and its other elements. This includes the more overarching academic approaches that align with the methodology, such as ontologies.

Paper V provides a recent framing of the socio-material flow methodology. Baumann (2004) presented a first call and outline for such a methodology Paper V formalises the methodology based on nine additional case studies on, among other, ice cream and packaging. The methodology is formalised in Paper V by listing and reasoning about the methodology’s types of study, five concepts, a procedure, an explorative and critical approach, and scopes. Previous publications on versions of the methodology have coined but not defined the concept of a socio-material interaction point (SMIP) (Baumann 2008), listed different scopes that the methodology can apply (Baumann et al 2015), and vaguely suggested possible types of study (e g, Baumann 2004).

The interest in broadening the ontologies and epistemologies used in material flow studies is introduced in Paper V in relation to the methodology. Ontologies and epistemologies are important to consider because they address the issues of why and how understanding is produced. This goes beyond the mere combination of different methods by responding to the question of what to study.

Paper V also provides the first outline of how the interest in an expanded ontological approach to man-made flows is translated to the socio-material flow methodology though the specific approaches actor-network-theory (ANT), object-oriented ontology (OOO), and agential realism. The approaches have partly been introduced in relation to the methodology, regarding ANT by Baumann (2004) and for PCO studies regarding OOO by Baumann (2012).

The conceptual contribution of the socio-material flow methodology is considered demonstrated in Paper V. The paper formalises and considerably extends previous publications.

9 Conclusion

This dissertation has presented the development and tests of a socio-material methodology for industrial ecology and change towards sustainability. The thesis was that such a methodology more accurately can help managers and policy-makers to identify and environmentally effectively influence change. Through the research presented and discussed throughout this dissertation, I conclude that the dissertation supports the thesis. This conclusion is based on my presentation of and reasoning about three topics: the calls for but limited other research on how nets of humans determine the environmental performance of man-made material flows (1); the identification in case studies of how a variety of complexities in the organising of the flows have environmental consequences (2); and the formulation of socio-material concepts and a methodology procedure that are based in existing hybrid ontologies and methodologies (3).

The methodology can be useful for decision-making because the methodology provides a recipe for documenting the complex and environmentally important interactions between actors that often are implicit in life cycle assessment (LCA) and other approaches in industrial ecology. Man-made flows do not flow by themselves.

Managers could benefit from socio-material consideration in reaching their reported intentions of caring for nature and reporting to the Global Reporting Initiative (GRI) each year. The methodology can be instrumental for creating a nuanced understanding of actual influence on environmental performance and rebound effects.

Not least, in the light of the current and expected sustainability challenges, different actors ought to manage the flows environmentally well. The socio-material methodology can provide guidance in this quest.

10 Further research

How could the socio-material flow methodology that this dissertation presents guide decision-making on the seemingly major current and expected environmental sustainability challenges?

The actual effect of the methodology on sustainability fully depends on how well users of the methodology comprehend it and manages to apply it. Descriptions of the methodology need to be accessible and brief, but must not become too void of the methodology’s critical approach and preciseness. Further research could lead to both reshaping of parts of the methodology and novel ways of presenting it.

Both calls for economic degrowth and issues of rebound effects relate to fundamental challenges in change towards sustainability (Parrique et al 2019). An assessment of the possibility for a combination of economic growth and environmental sustainability suggested degrowth as a likely needed option in richer countries. The publication concludes that, among other, rebound effects, and shifting of environmental burdens to other locations and other environmental issues makes continued economic growth environmentally unsustainable. Degrowth may in turn require large-scale joint action where the combined effect of all activities and the change of them is a central issue. The socio-material flow methodology can, by its combination of naturalistic, interpretative, and critical approaches to action nets and man-made flows be used to find and avoid side-effects of different actions, but only if applied with a scope that is not delimited regarding time horizon and geographical considerations. Chain effects could be difficult to study, but the findings can be highly rewarding if they provide critical knowledge on change toward sustainability.

Glossary

Name	Type	Explanation
Action net	Research concept	An often inter-organisational web of organisational processes
Actor LCA		See *actor life cycle assessment*
Actor life cycle assessment	Variant of the socio-material methodology	A *socio-material flow methodology* variant that is used for combining thorough studies of *product life cycles* with *action nets* studies that focus on how actors along the flow can influence each other
Actor-network-theory (ANT)	Research approach	*Posthumanist* approach that considers that humans are dependent on material objects to perform actions as well as constrained by these objects
Agential realism	Research approach	*Posthumanist* approach based on a view of the world as constructed through actions between more than one object
ANT		See *actor-network-theory*
Broad PCO study		See *broad product chain organisation study*
Broad product chain organisation (broad PCO) study	Variant of the socio-material methodology	A *PCO study* variant where all *product life cycles* that relate to, for example, a certain type of product are covered
LCA		See *life cycle assessment*
In-depth LCNO study		See *in-depth life cycle nodal organisation study*
In-depth life cycle nodal organisation (in-depth LCNO) study	Variant of the socio-material methodology	An *LCNO study* variant where a thorough study is performed
LCNO study		See *life cycle nodal organisation study*
LCM		See *life cycle management*

Life cycle assessment (LCA)	Methodology and tool	For assessing as fully as possible the potential environmental impacts of a *product life cycle*
Life cycle management (LCM)	Umbrella concept	Managerial approaches related to *LCA* and developed in or close to the *LCA* community
Life cycle nodal organisation (LCNO) study	Variant of the socio-material methodology	A *socio-material flow methodology* variant that is used for studies of the *action nets* traced from *product life cycle* nodes where environmentally important man-made flows meet
Man-made flow	Concept	Transfers and use of materials and energy created by humans
Material flow analysis (MFA)	Method and tool	For studying the *man-made flow* of one specific material
Material flow study	Concept	The study of a *man-made flow*. This can be carried out through, for example, *LCA* and *MFA*
MFA		See *material flow analysis*
Object-oriented ontology (OOO)	Research approach	*Posthumanist* object-based philosophy that stems from phenomenology
OOO		See *object-oriented ontology*
PCO study		See *product chain organisation study*
Posthumanist	Analytical concept	Represents that social and material aspects are treated as equally important
Product chain organisation (PCO) study	Variant of the socio-material methodology	A *socio-material flow methodology* variant that is used for studying *action nets* along entire *product life cycles*
Product life cycle	Concept	The *man-made flow* necessary for producing, using, and management the waste of a product
Screening LCNO study		See *screening life cycle nodal organisation study*
Screening life cycle nodal organisation (LCNO) study	Variant of the socio-material methodology	An *LCNO study* variant where a quick overview study is performed
Single PCO study		See *single product chain organisation study*

Single product chain organisation (single PCO) study	Variant of the socio-material methodology	A variant of a *PCO study* where one *product life cycle* is covered
SMIP		See *socio-material interactions point*
Socio-material	Analytical concept	Represents that humans and material objects are seen as inseparable
Socio-material flow methodology	Analytical methodology	A methodology on a *posthumanist* and *socio-material* combinations of *material flow studies* and studies of *action nets*
Socio-material interactions point (SMIP)	Analytical concept	Environmentally relevant connection between an *action net* on one side and a *man-made flow* on the other side

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